Using Feature-Based Methods to Improve Tropical Cyclone Forecasts

in the National Blend of Models

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November 19, 2020

Motivation

To better incorporate Direct Model Output (DMO) from Hurricane models and the official gridded Tropical Cyclone forecast Message (wTCM) product from the National Hurricane Center (NHC) into National Blend of Models (NBM) wind speed forecasts.

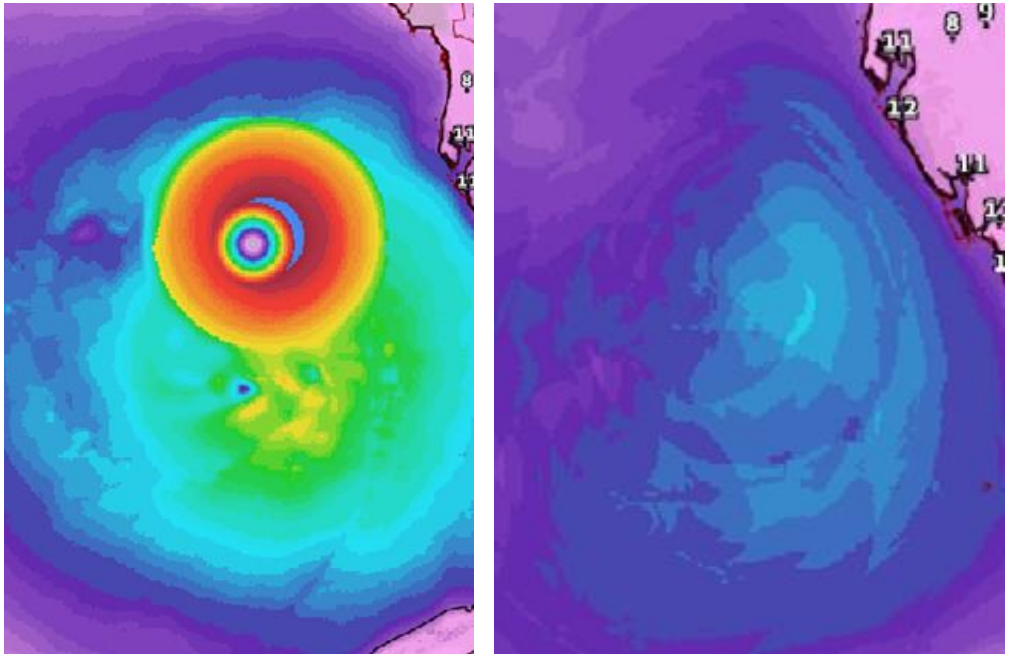
Specifically:

- We want to avoid washing out wind speed magnitudes.
- We want to leverage all the information we have from the inputs to create a single, coherent forecast feature to place on the NBM forecast background.
- We want to maintain the integrity of the official NHC forecast (wTCM) when available.

So….what do we mean by that?

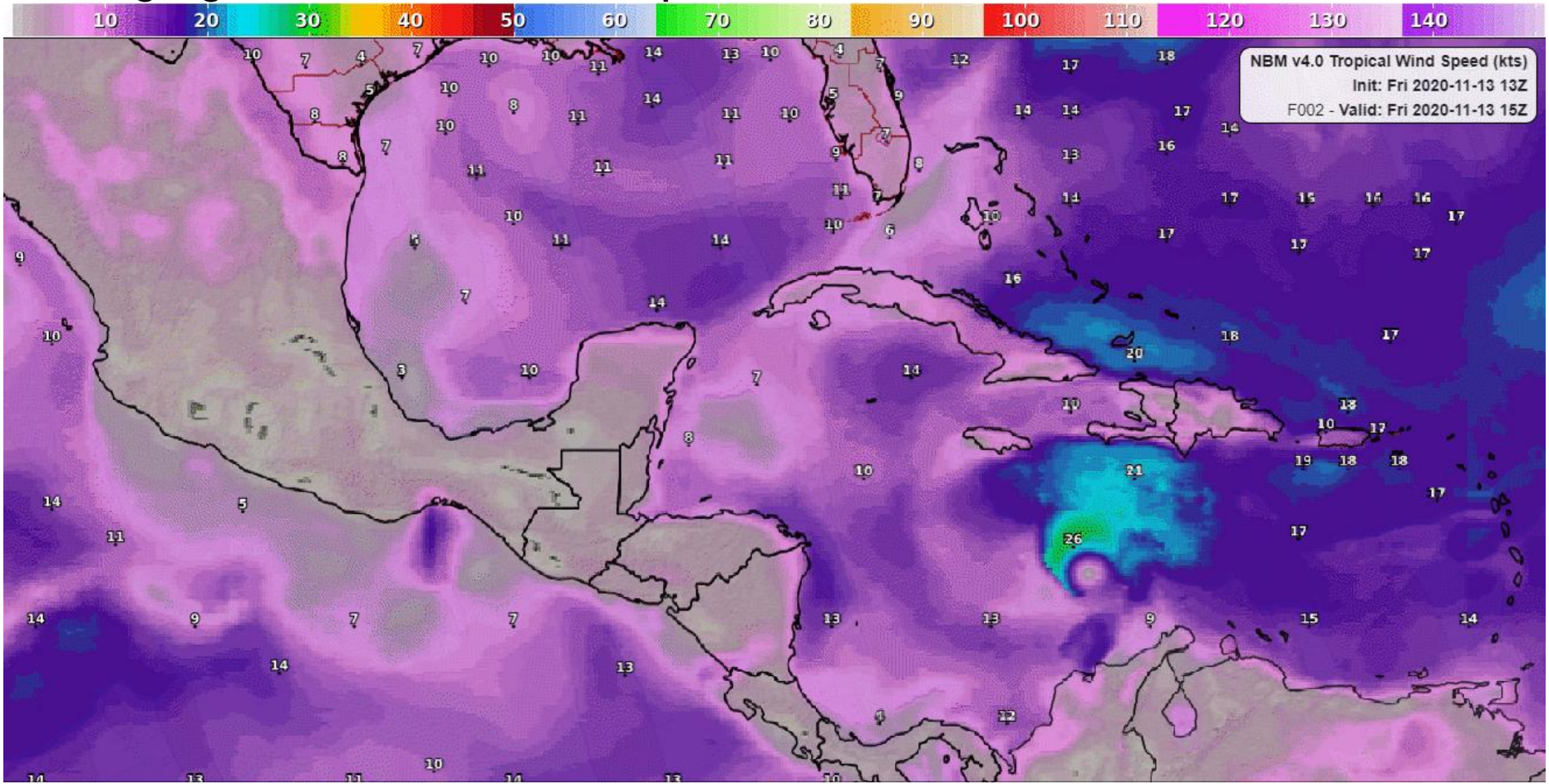
Motivation

NBM 4.0 Tropical Wind Speed (Left) and 10m Wind Speed (Right)
Tropical Storm Eta
2020 11 09 13z Cycle - 68 hour Forecast



- Grid-based (Mean Absolute Error/Expert weighting of input forecasts) can create some odd forecasts for high magnitude forecast features such as TCs.
- Magnitudes of blended models tend to be washed out (note lower magnitude, secondary cyclone south of wTCM forecast).
- Can get multiple eyes and much broader wind field.
- Conversely, a weighted average of global models may not represent the cyclone at all.

Diverging Forecasts can be a problem



Motivation (continued)

- Feature-based (alternately referred to as object-based) techniques that take individual features of interest from a whole-domain forecast are not a new concept. Tools exist to perform tasks like verification based on these methods already (Model Evaluation Toolkit's MODE tool, for example).
- By applying this concept to blending forecast inputs, we can combine the representation of the TC from various models by combining them over their respective centers, preserving magnitude.
- These "hybrid" features can then be placed on a background forecast (NBM Wind Speed in our case) at a specific location.

What this technique IS:

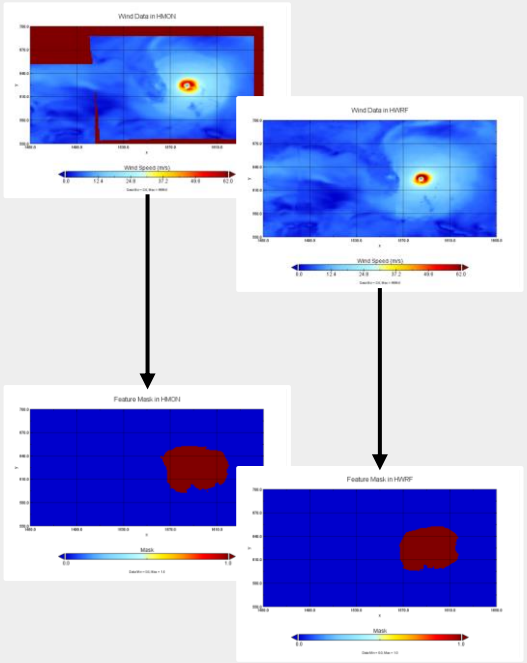
- A collection of simple techniques to apply feature-based concepts to Blending forecasts from multiple input models.
- An algorithm that makes decisions on combining features of interest based on empirically decided thresholds and fuzzy (non-binary) logic added for matching.
- *A specialized tool to address the requirements of NBM and to apply specific rules to preserve the wTCM forecast when available.*

What this technique is NOT:

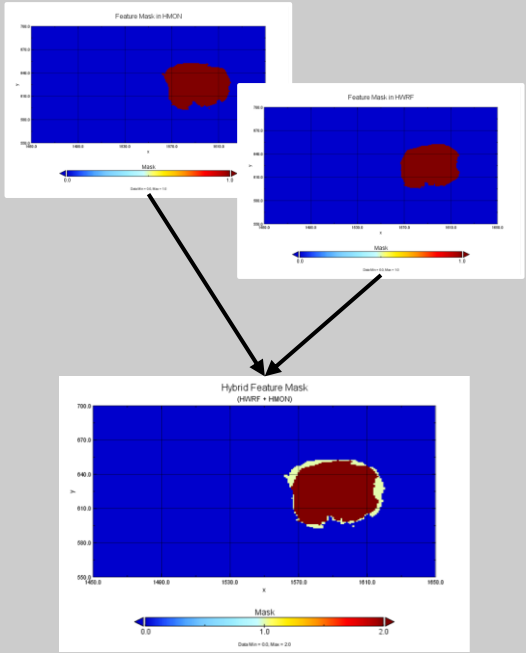
- A physical, dynamical, or statistical model that considers the structure of the TCs as we combine them.
- Machine learning (although there is certainly opportunity to apply this to assist with classification and matching).

Process Overview (Rough)

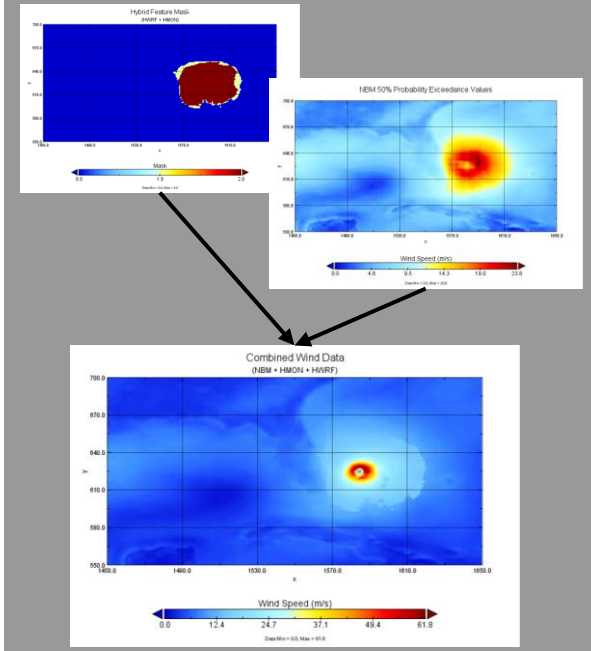
Identify



Combine



Place



Process Overview

1	Identify Features
2	Feature Adjustments
3	Match Features
4	Build Hybrid Features
5	Place Hybrids on Background

“Is This a Feature?” Thresholds

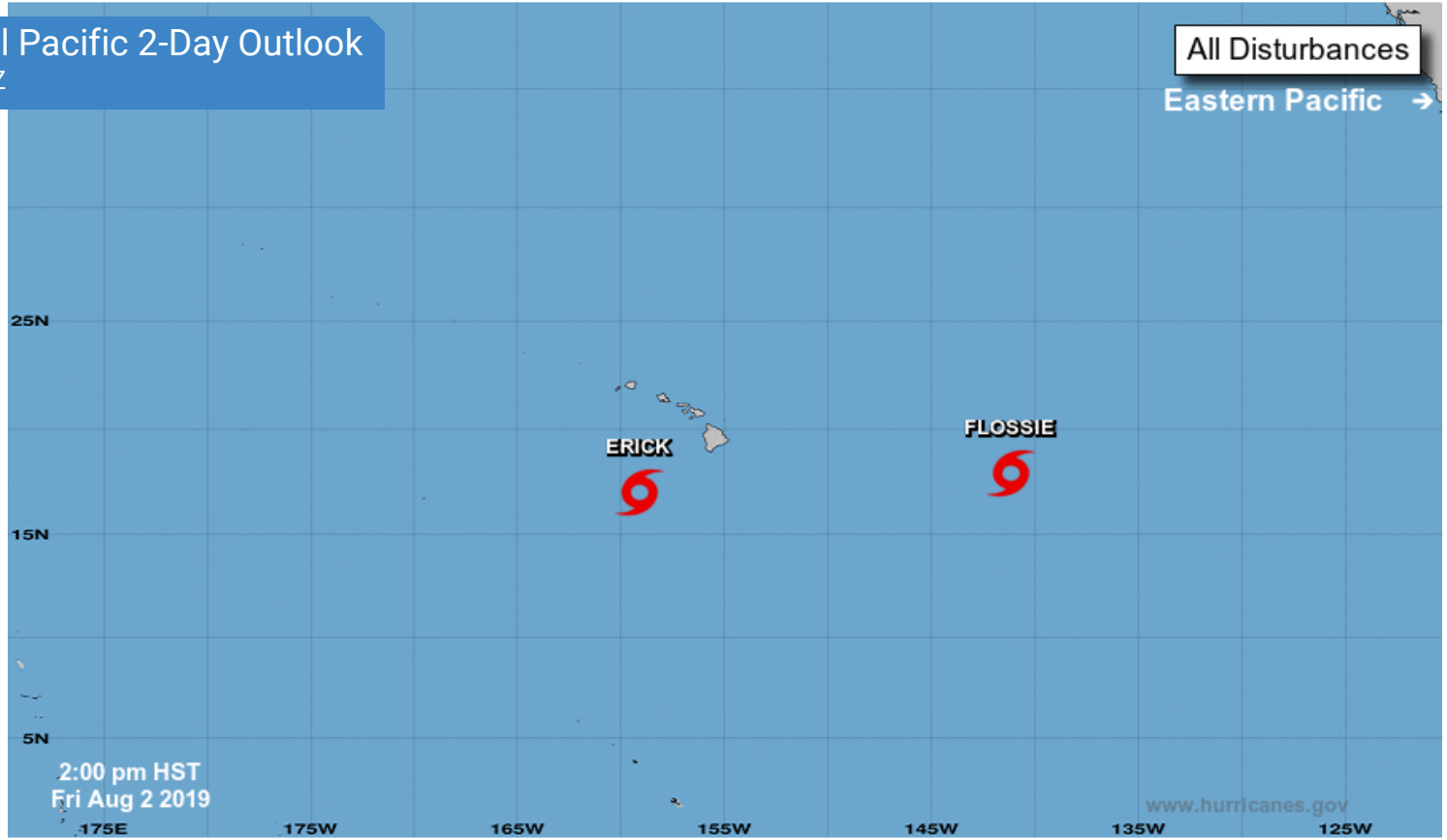
	Threshold
DMO (HWRF/HMON)	>= 14.0 m/s
wTCM	>= 14.0 m/s *preserved at >= 17.49 m/s

Five-Day Graphical Tropical Weather Outlook

Central Pacific Hurricane Center Honolulu, Hawaii

NHC Central Pacific 2-Day Outlook

20190803 0245Z



Current Disturbances and Five-Day Cyclone Formation Chance: < 40% 40-60% > 60%

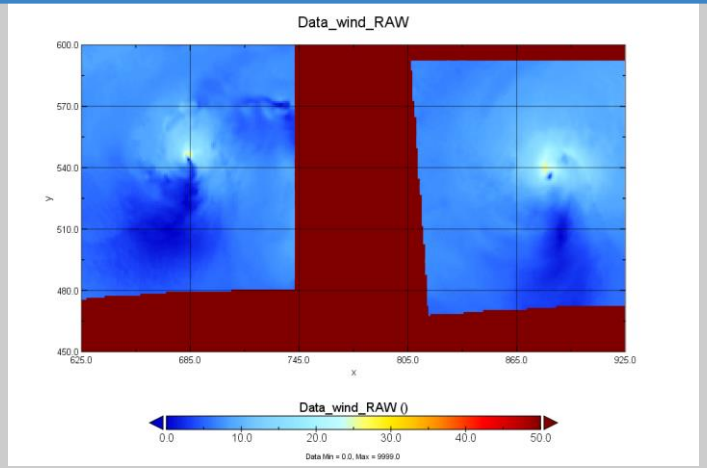
Tropical or Sub-Tropical Cyclone: Depression Storm Hurricane

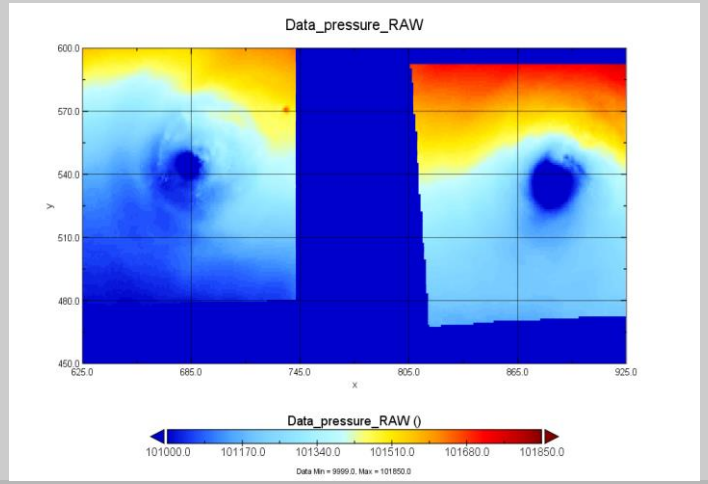
Post-Tropical Cyclone or Remnants

HMON and HWRF 30-Hour 10m Wind Speed and MSLP

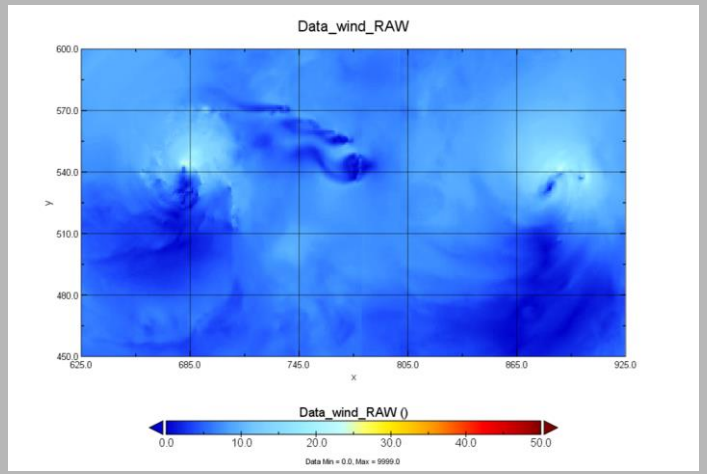
20190803 00z Run

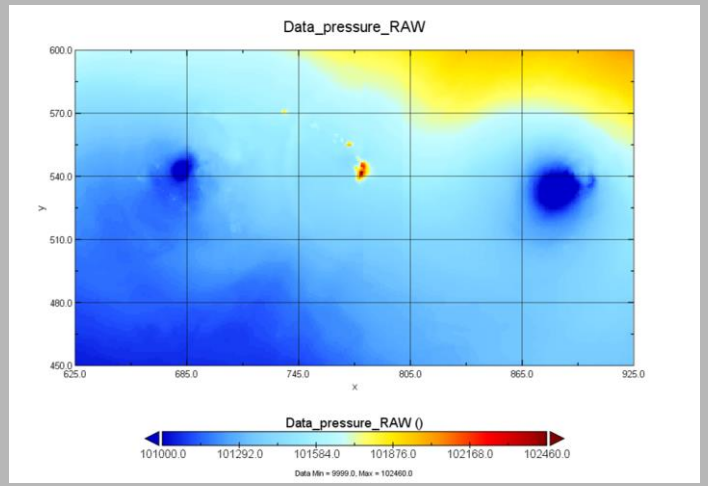
HMON





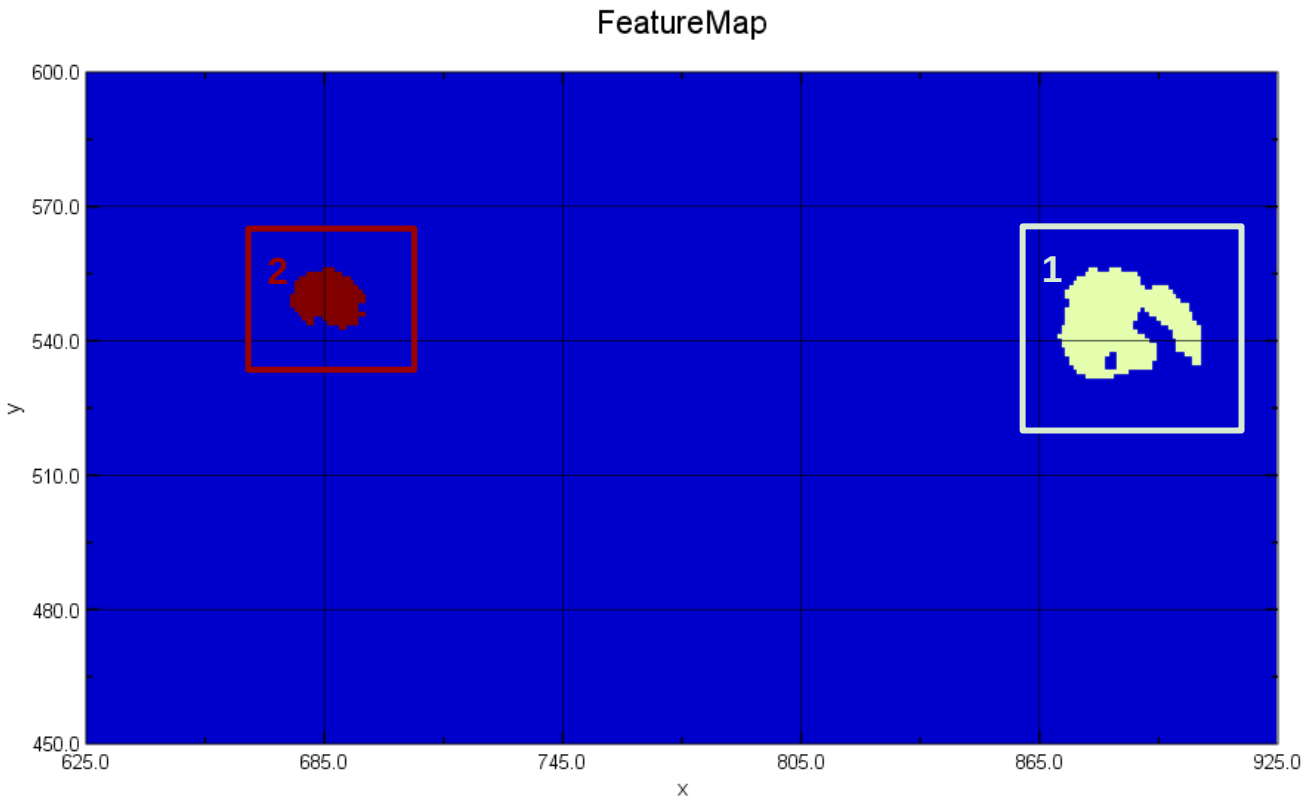
HWRF





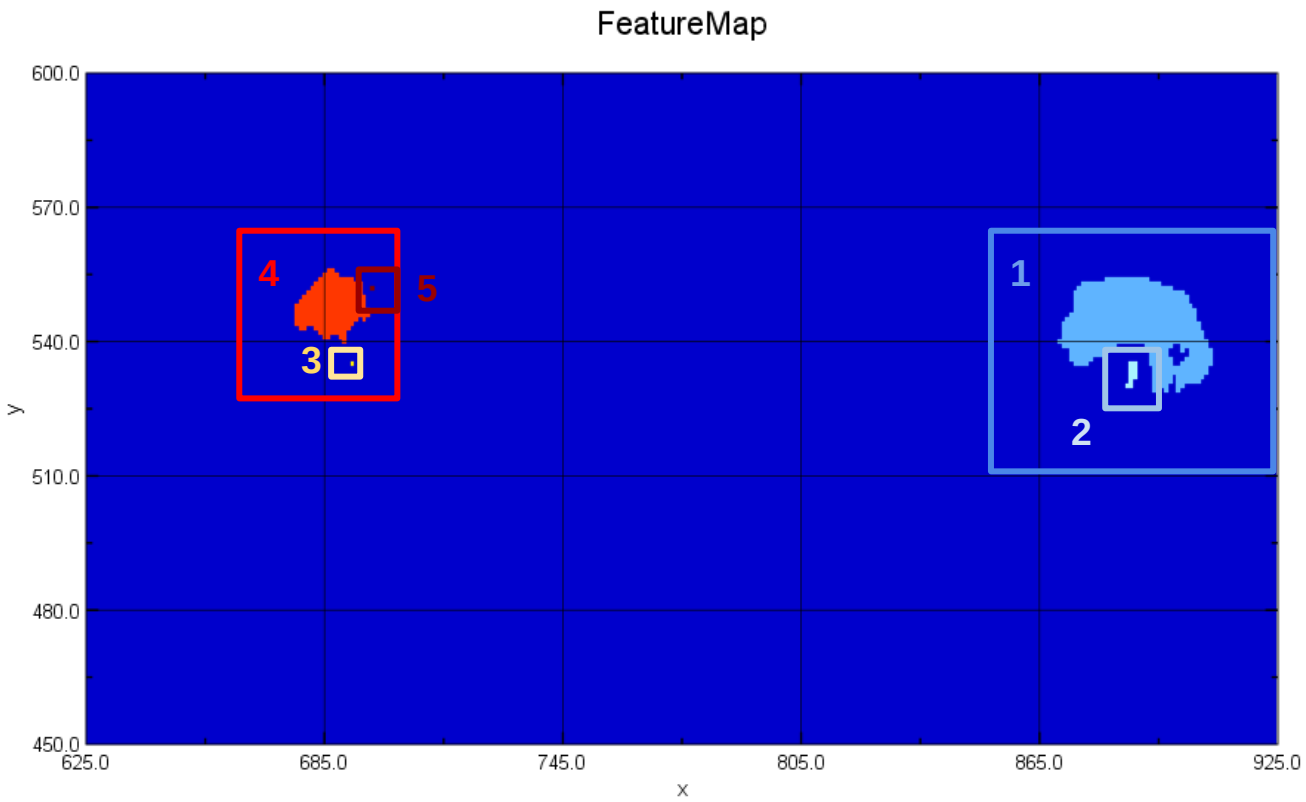
HMON 30-Hour Forecast Features

20190803 00z Run



HWRF 30-Hour Forecast Features

20190803 00z Run



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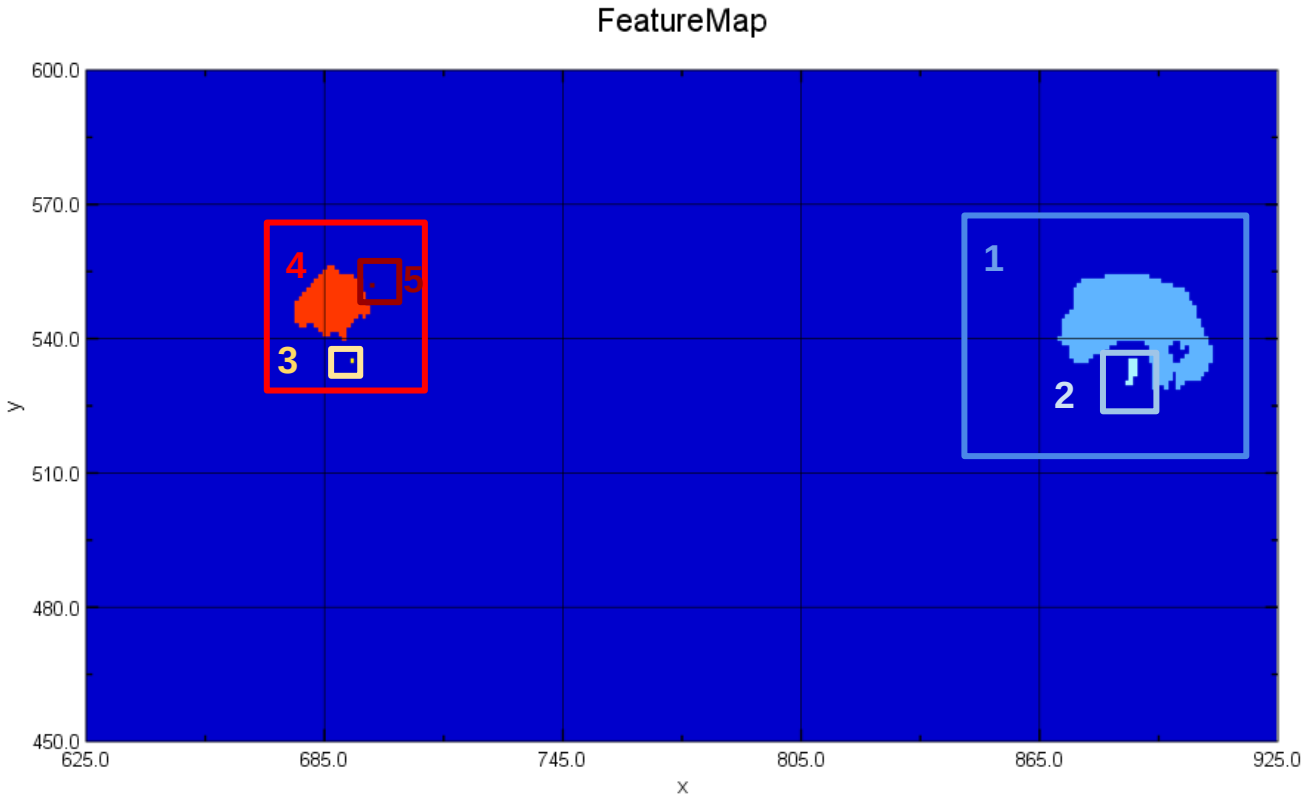
2 Feature Adjustments

- At this point it is helpful to make a few tweaks to input features before we try to match between models. Primarily:
  - Combining nearby features to reduce noise and group together “features” that are actually part of the same meteorological feature.
  - Fill in gaps within a feature (such as the eye).
- **Once we’ve completed this step, a “Feature” as defined by the code should be representative of a true meteorological feature (e.g., each feature represents a Tropical Cyclone).**
- From this point on we operate on Features on their own subgrid, essentially pulling them off the larger domain grid.

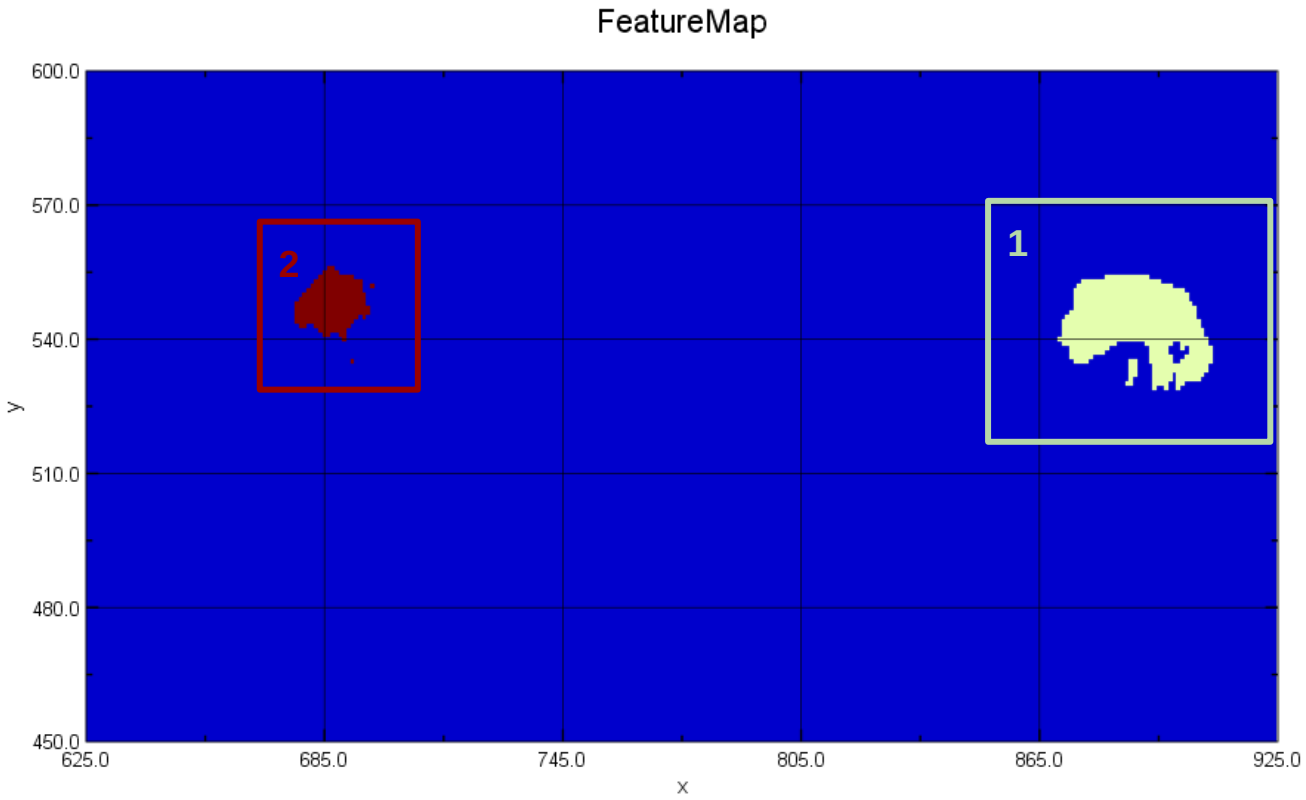
HWRF 30-Hour Forecast Features

Before Combining



HWRF 30-Hour Forecast Features

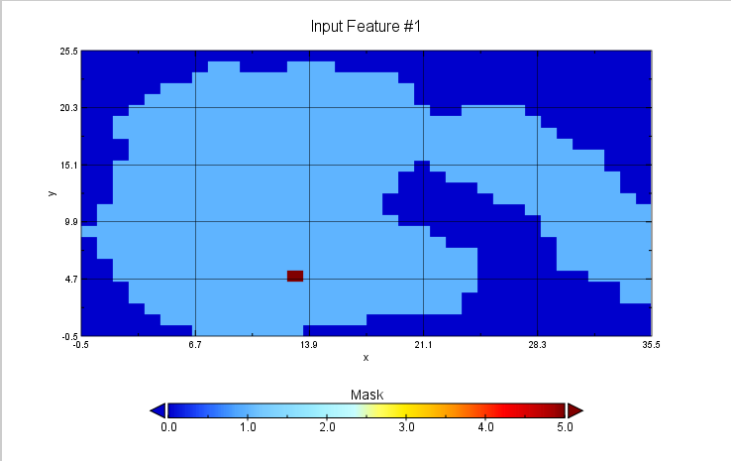
After Combining

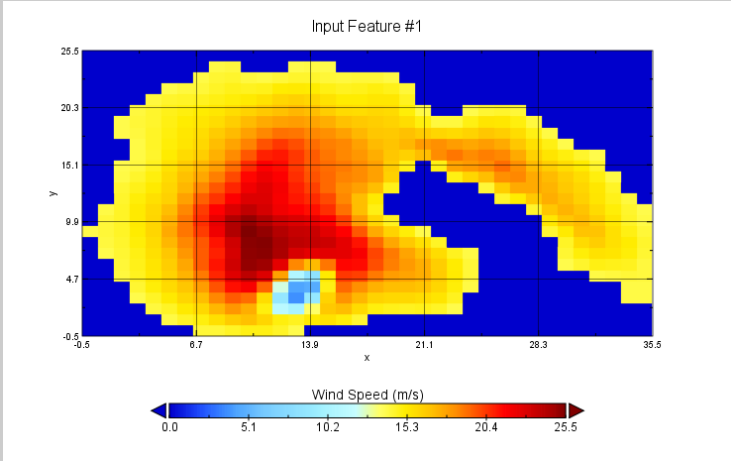


TS Flossie Features

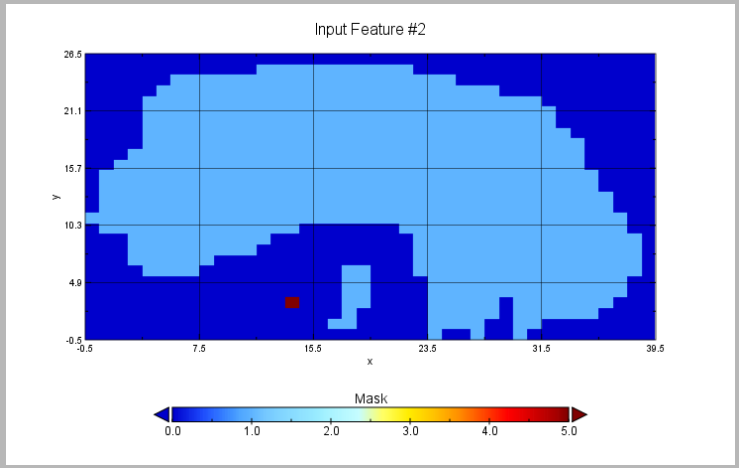
Mask and Wind Speed Data (HWRF & HMON)

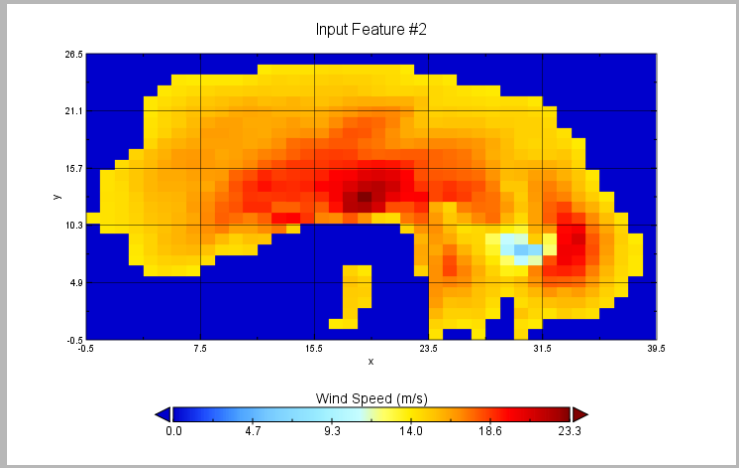
HMON





HWRF

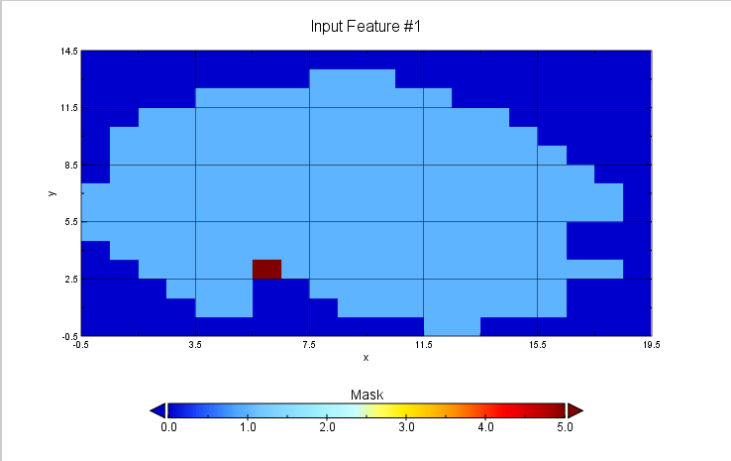


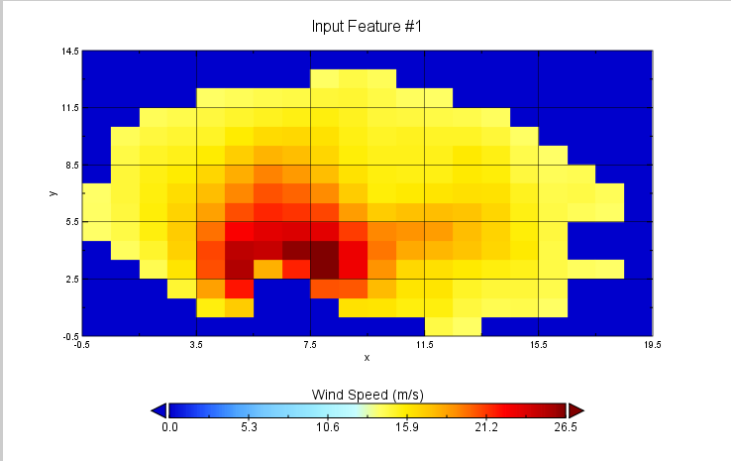


TS Erick Features

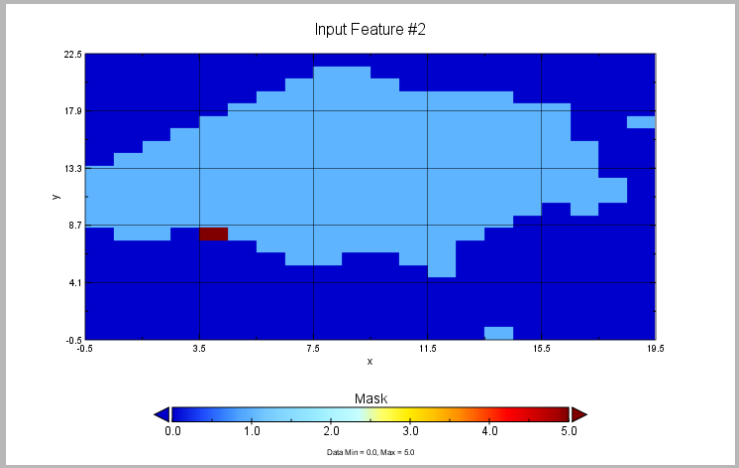
Mask and Wind Speed Data (HWRF & HMON)

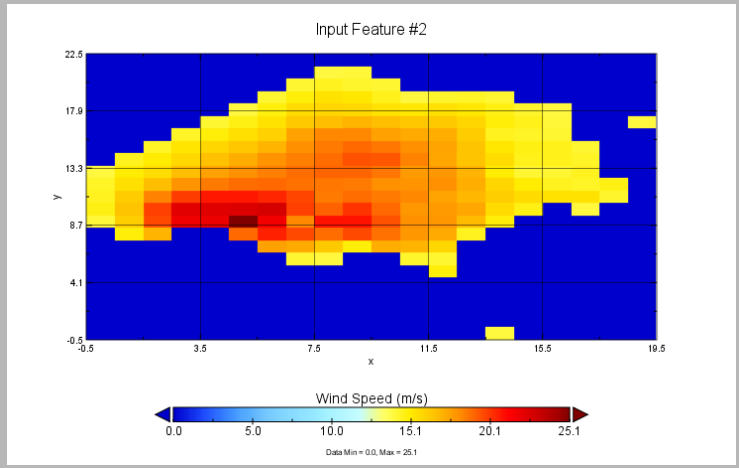
HMON





HWRF





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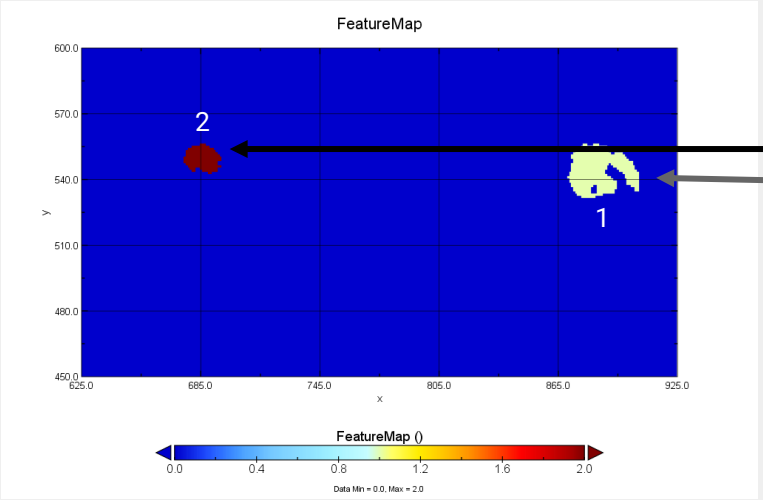
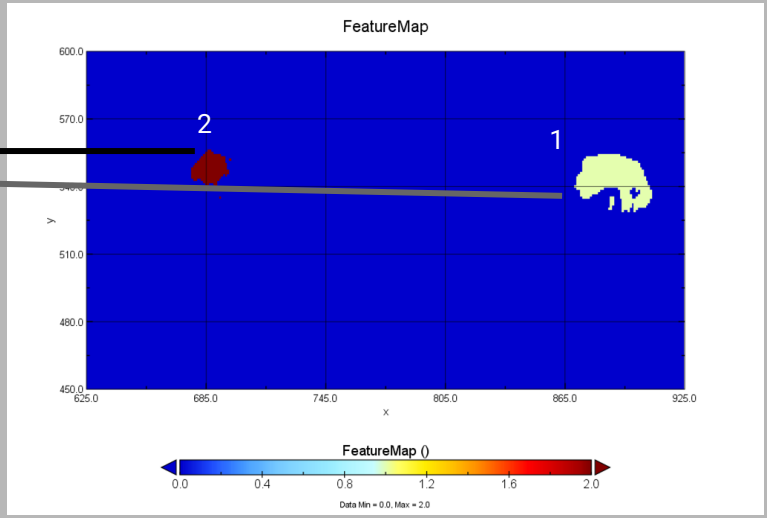
3 Match Features

- Now we have a list of features associated with each model forecast.
- The next step is to iterate over the list of features for each input model, and calculate a match score between it and each feature in the other input models.
- Match scores are the mean of three component scores which are the normalized difference between the two features in three logical criteria:
  - Distance* (based on minimum pressure when available, or minimum central wind speed),
  - Size (based on area, counted in gridpoints),
  - Magnitude (based on mean wind speed within the feature area).
- Component scores are normalized by largest value to reduce influence from scale/units.
- Scores near zero indicate the best match (least difference).

*Distance score currently receives double weight

Matching Results HWRF
Feature Map Comparison





	HMON Matching Feature Number
HWRF Feature #1	1
HWRF Feature #2	2

HMON

HWRF

Process Overview

1	Identify Features
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4 Build Hybrid Features

Now that we've determined the match score and best match for each feature we have all the information we need to build Hybrid Features -- which are the single features that combine the various model inputs for a specific TC, and what we will be placing back on the background forecast.

The first step of doing that is to collapse information into a single table to determine the total number of Hybrid Features to generate and specify which TC features from each model to use in each Hybrid Feature.

- ➔ Our current method constrains the number of hybrid features to number of features present in the model with the least total features.
- ➔ Most typically this will be the wTCM.
- ➔ The intent of this is to only generate Hybrid Features where we are likely to have agreement across all input models.

Sample Hybrid Table

2 Hybrid Features will be created

	Model 1	Model 2	Model 3
Feature 1	1	1	1 (Highest Score)
Feature 2	2	2 (Highest Score)	1 (Lowest Score)
Feature 3	--	2 (Lowest Score)	2 (Lowest Score)
Feature 4	--	--	2 (Highest Score)
	2 Features 0 Duplicate Matches	**3 Features 1 Duplicate Match**	**4 Features 2 Duplicate Matches**

Total number hybrid features determined by model with fewest features

4 Build Hybrid Features

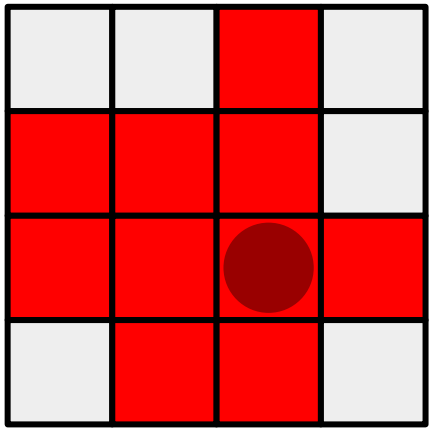
Now that the number of Hybrid Features and their corresponding inputs have been determined, we can begin combining the features. We do this by:

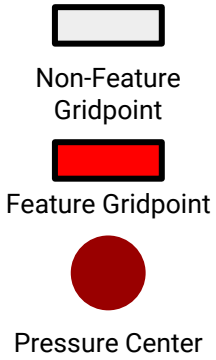
1. Defining a new gridspace for each Hybrid Feature that is large enough to contain the input TC features from each model when they are stacked on the center point.
    a. The Hybrid Feature grid subgrid is just a snip of the full domain grid at the same resolution.
2. Building a Hybrid Feature Mask to determine where and how much overlap we have between input TC features.
3. Calculate the final hybrid Wind Speed feature grid and location.

Building the Hybrid Grid and Mask

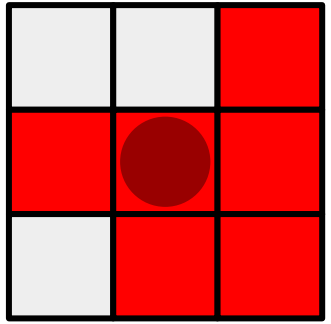
Fitting input features of different extents

Feature 1





Feature 2



NX	4
NY	4
Center Location	(3, 2)
Center on Map*	(1876, 15)

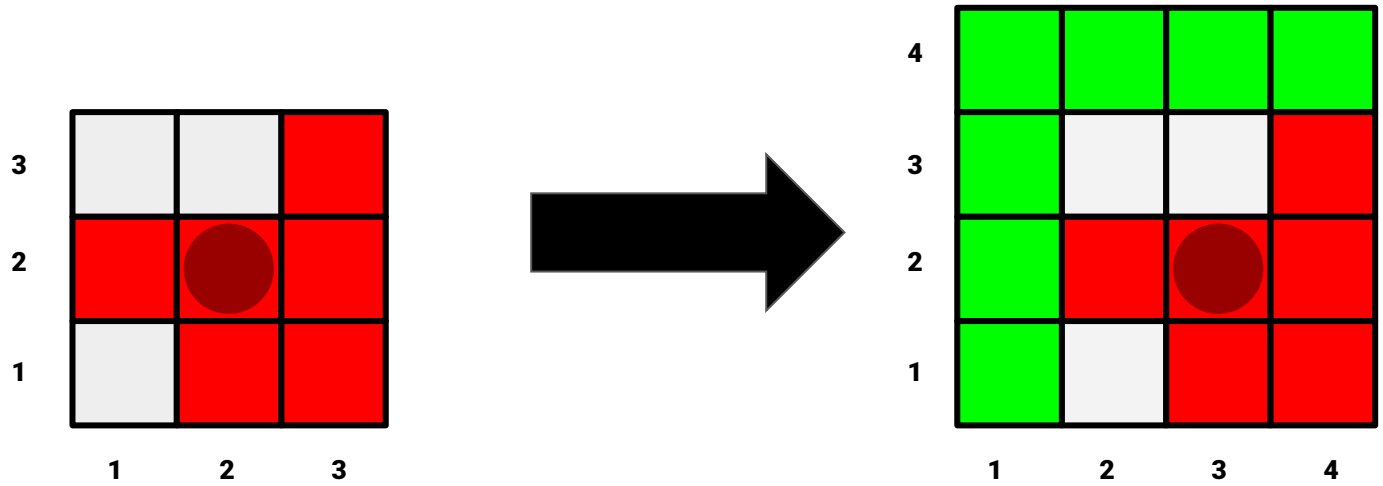
NX	3
NY	3
Center Location	(2, 2)
Center on Map*	(1822, 25)

* For this example these are completely fictitious coordinates on the CONUS grid

Building the Hybrid Grid and Mask

Fitting input features of different extents

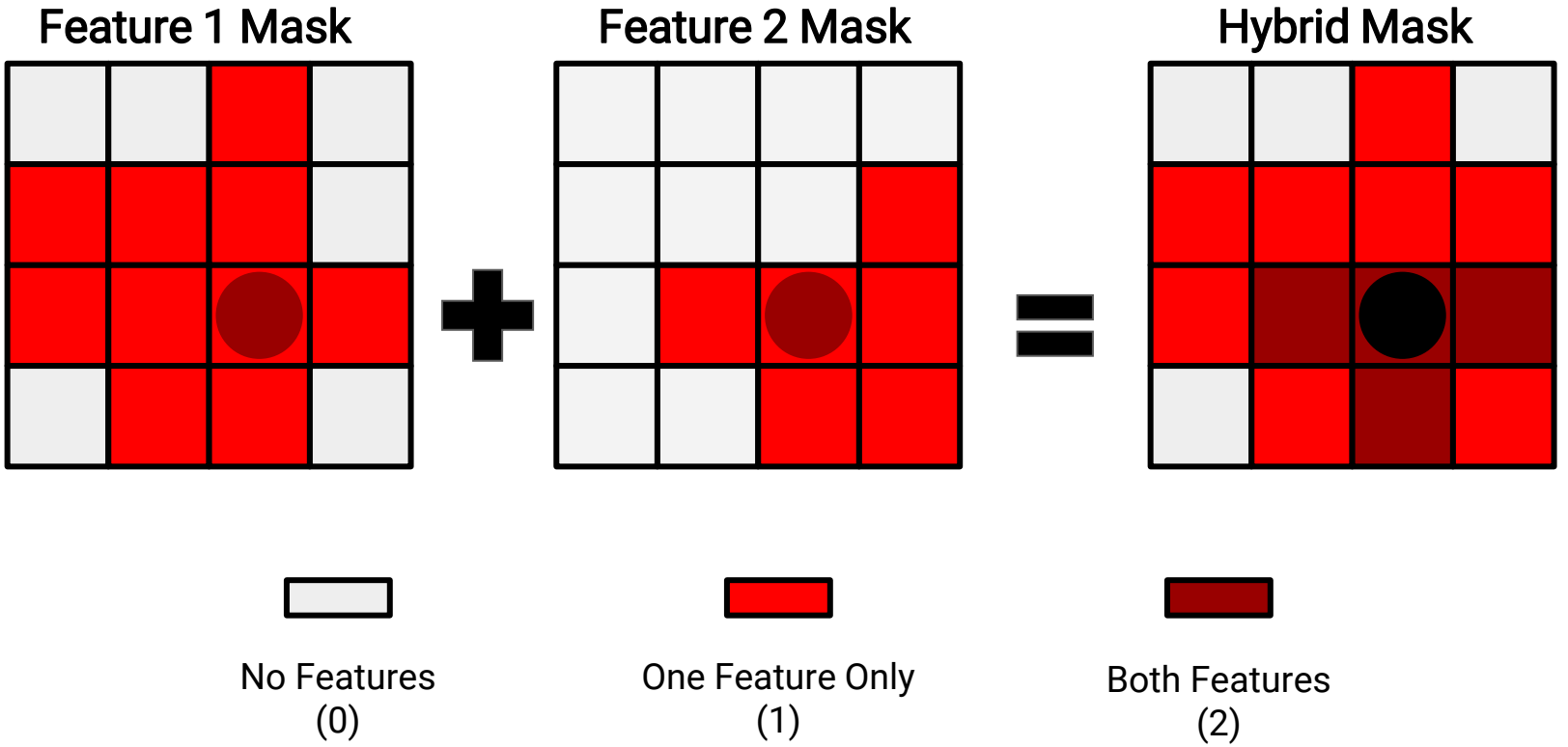
First we need to create a hybrid grid space the covers the combined area of both features extending out from the center point:



In this case all of Feature 2 can fit entirely on the subgrid for Feature 1, so only feature 2 needs adjustment, and Feature 1 will translate directly onto the hybrid grid space.

Hybrid Mask
Combining Translated Feature Masks

Stacking by center location, we get a combined mask on the hybrid grid space:



Creating Hybrid Wind Speed

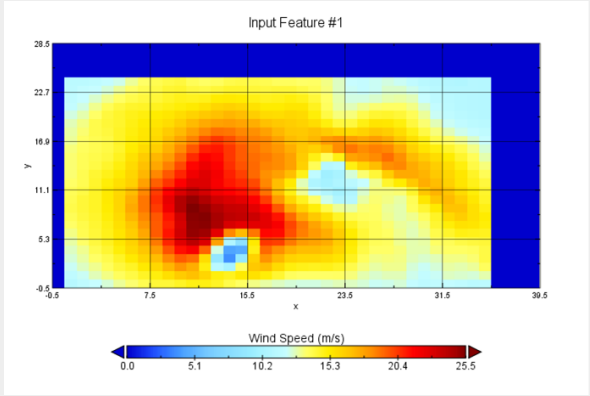
When wTCM is Present:

1. *Mean speed calculated at each gridpoint, based on number of input models*
2. *Cap all values at a maximum of 33.9 kts and then place wTCM values >33.9 kts back on top*
3. *Smooth boundaries between differing numbers of features*
4. *Run check on non-wTCM values > 33.9 kts and re-assert wTCM > 33.9 kts*

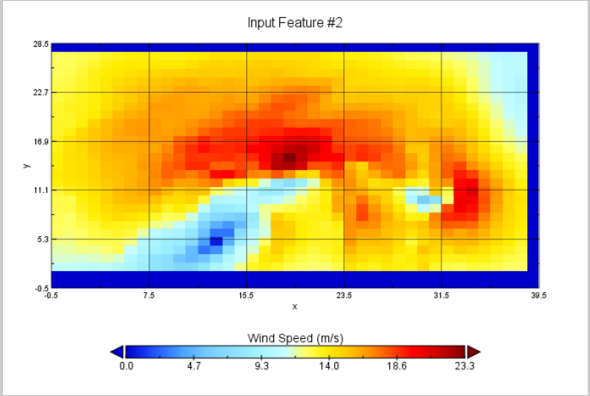
When wTCM is Not Present:

1. *Mean speed calculated at each gridpoint, based on number of input models*
2. *Smooth boundaries between differing numbers of features*

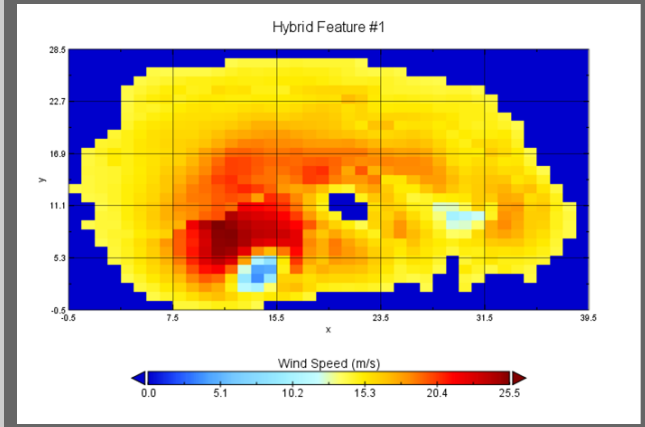
Build Hybrid Feature: TS Flossie



HMON

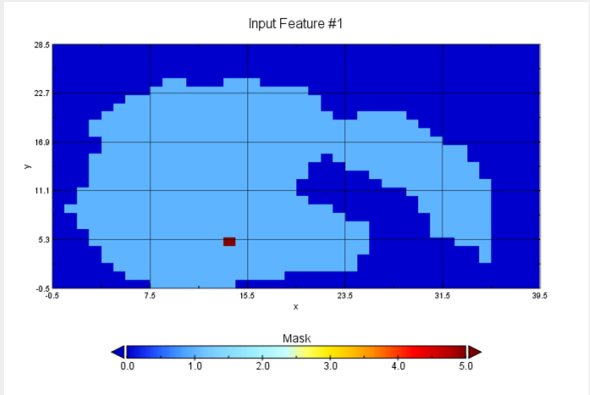


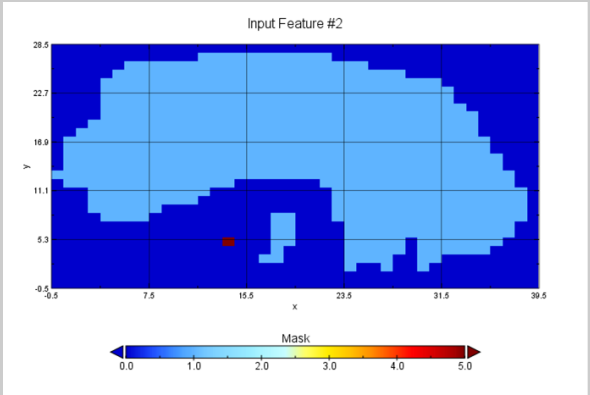
HWRF

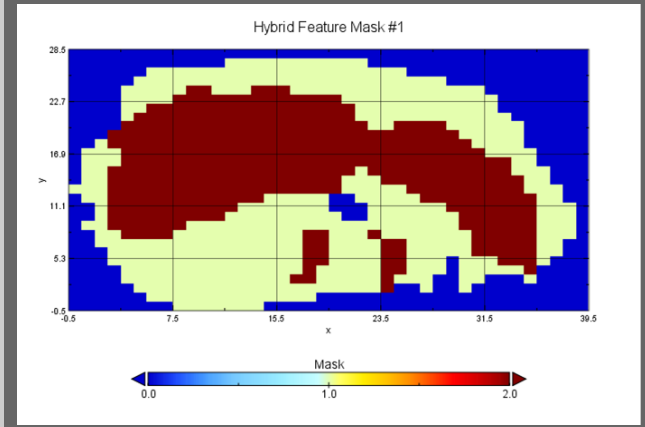


Hybrid Feature

Data

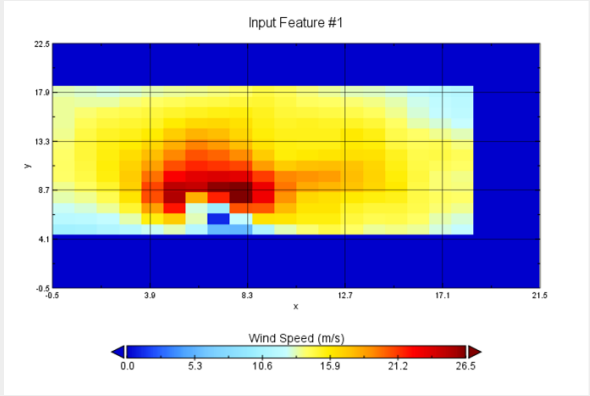




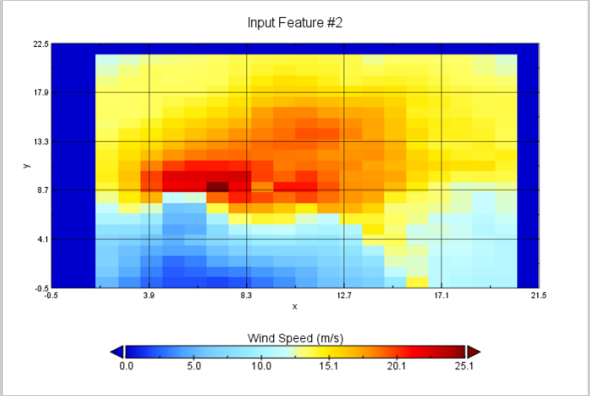


Mask

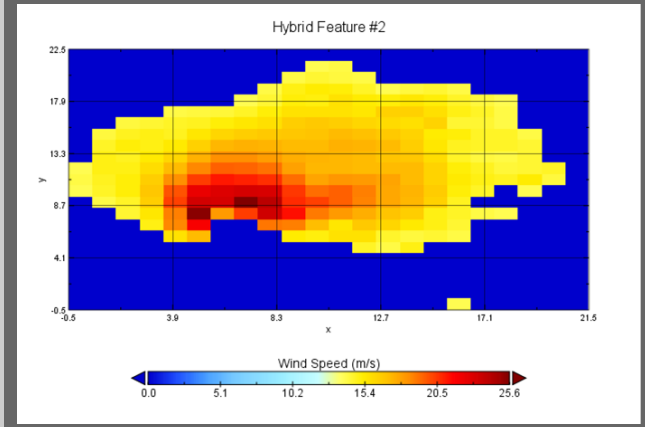
Build Hybrid Feature: TS Erick



HMON

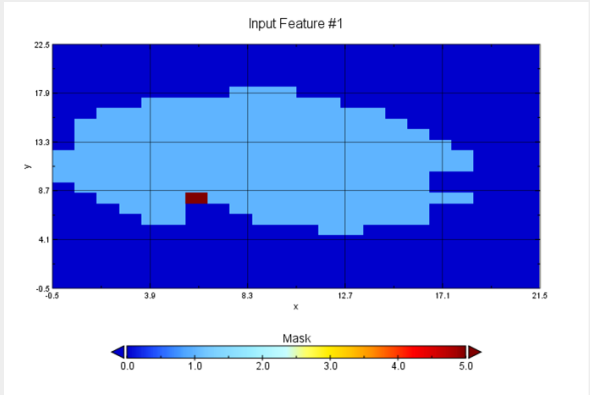


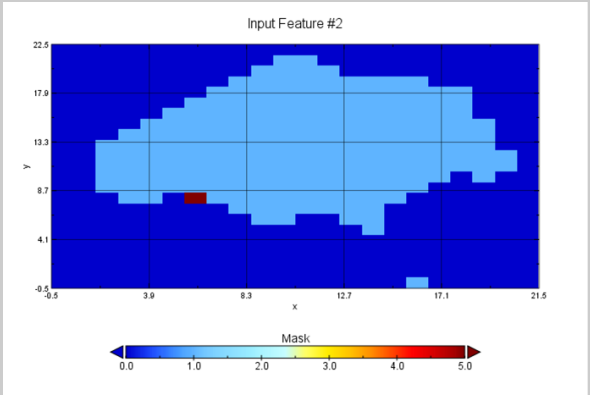
HWRF

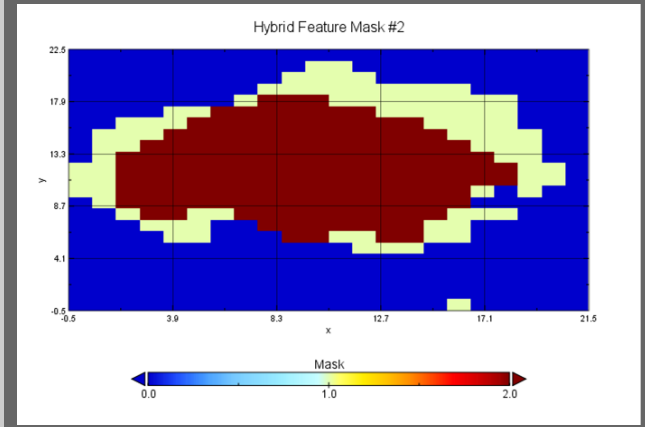


Hybrid Feature

Data

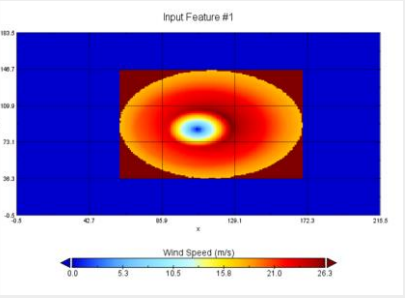




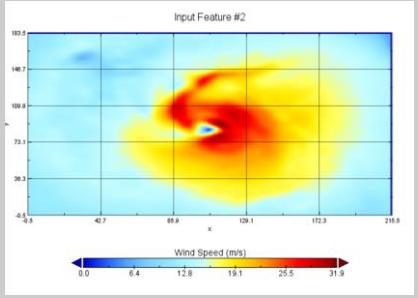


Mask

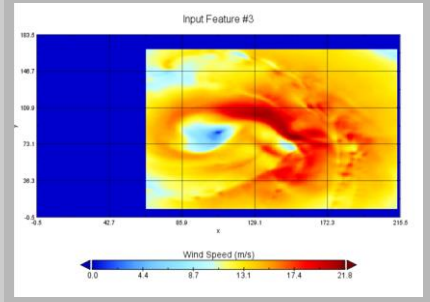
Build Hybrid Feature: TS Eta



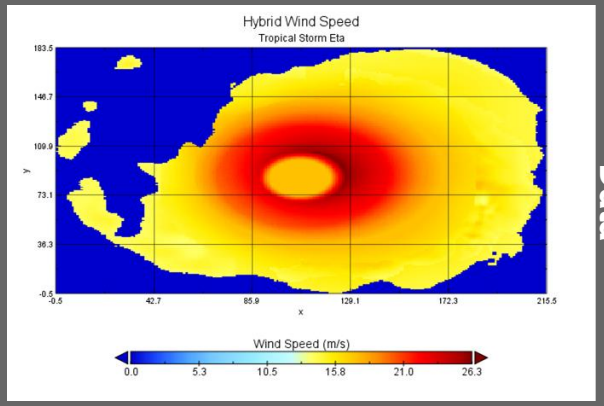
WTCM



HWRF

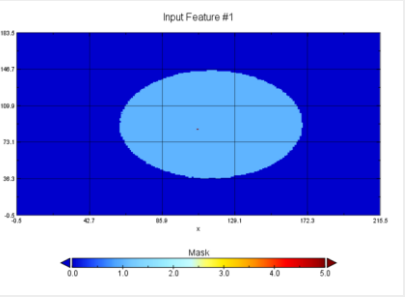


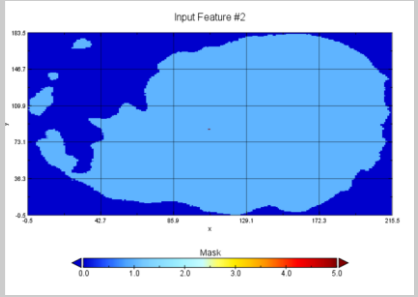
HMON

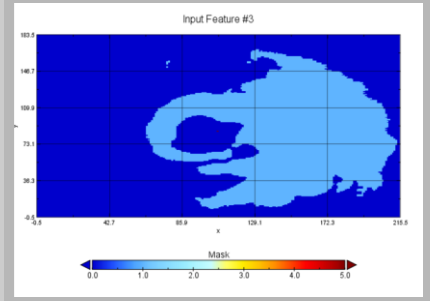


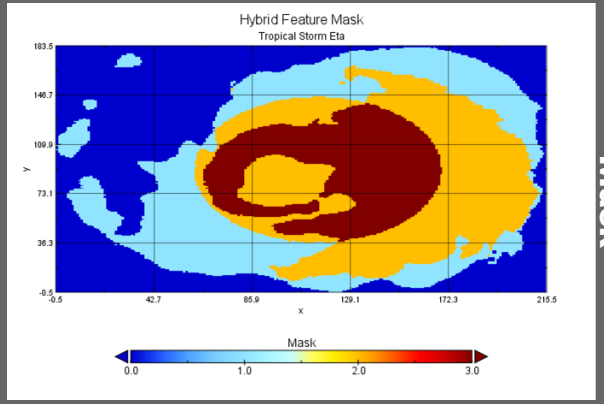
Hybrid Feature

Data









Mask

Determining Feature Location

When wTCM is Present:

➔ *Hybrid Features placed at wTCM center location*

When wTCM is Not Present:

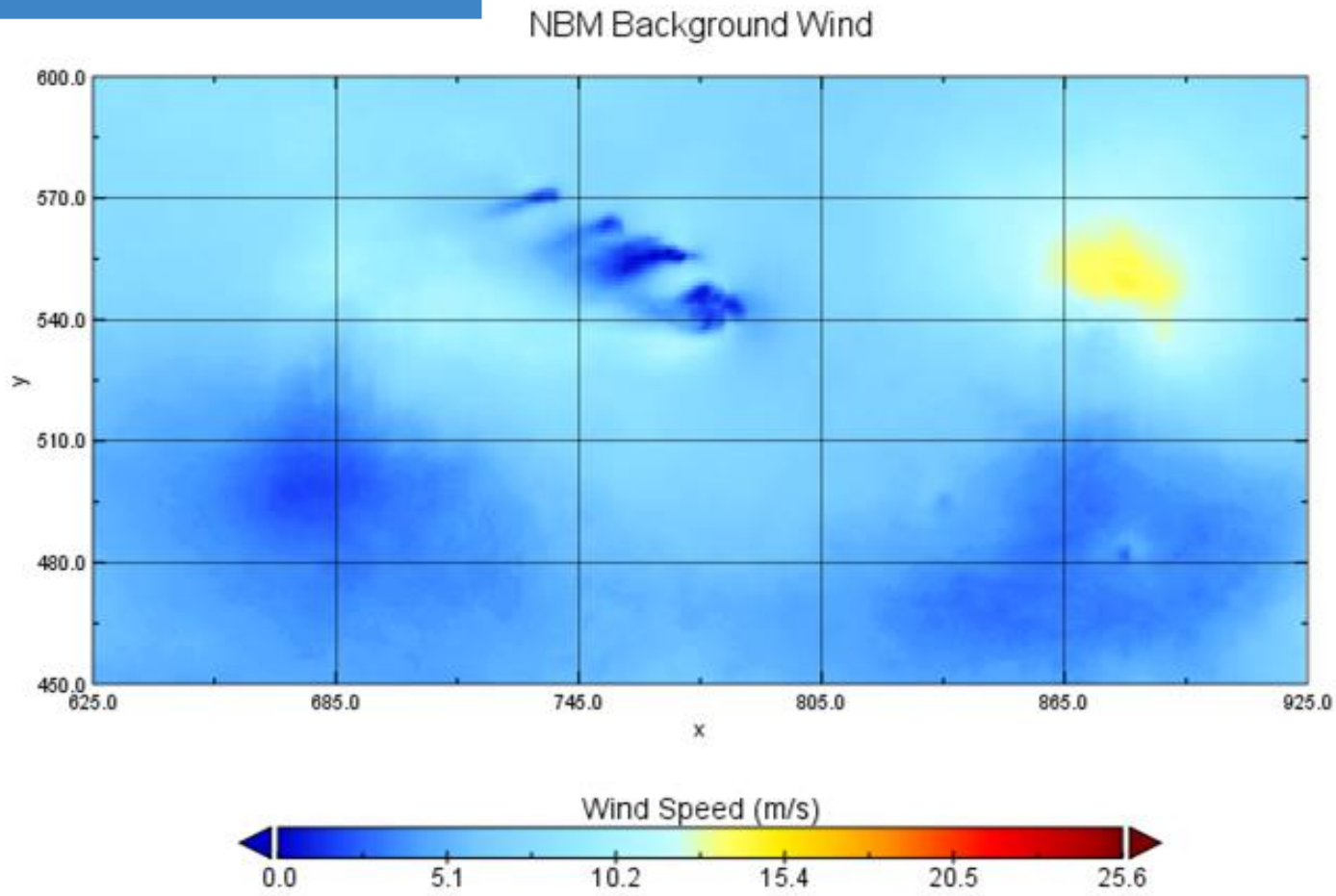
➔ *Hybrid Features placed at mean center location of all inputs*

- Currently equal weight, but can be weighted if desired

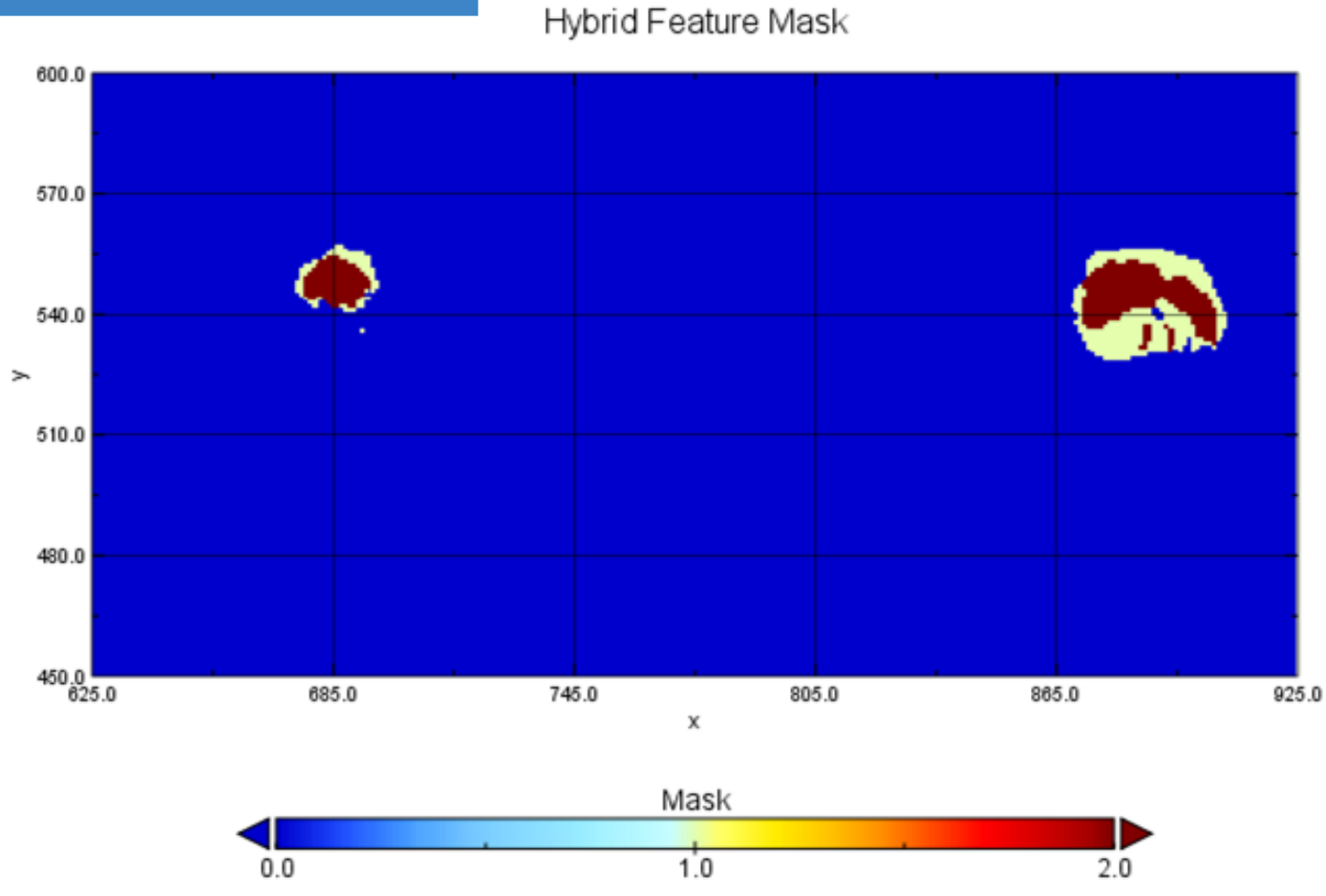
Process Overview

1	Identify Features
2	Feature Adjustments
3	Match Features
4	Build Hybrid Features
5	Place Hybrids on Background

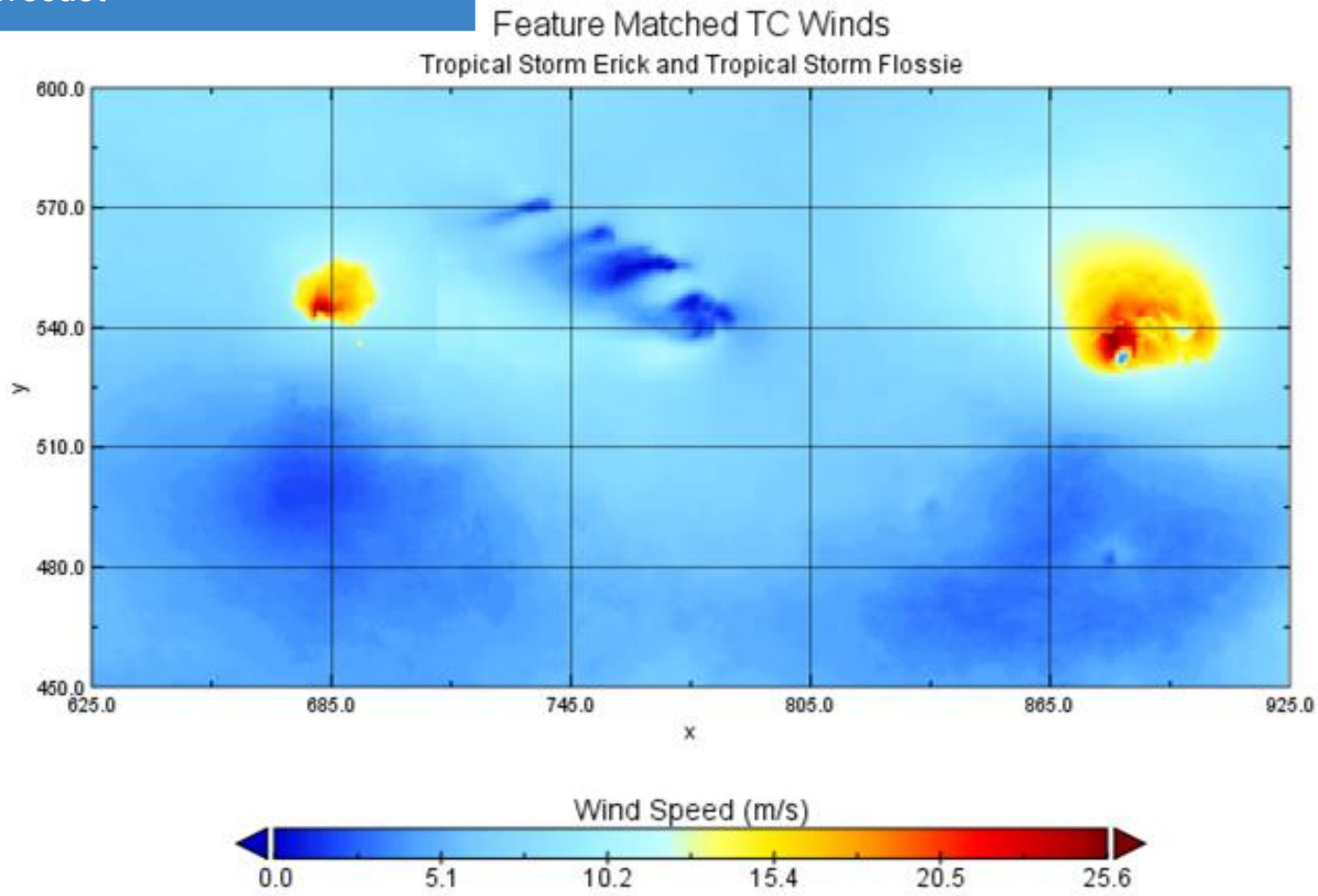
NBM 50% Probability Exceedance Wind



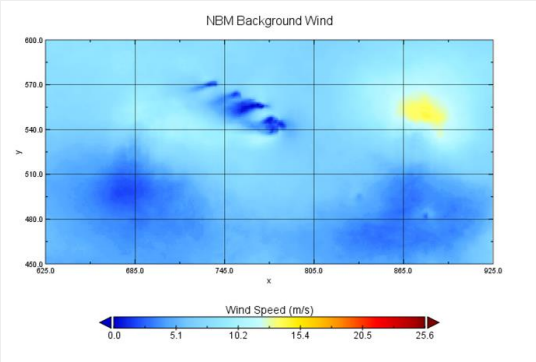
Hybrid Feature Mask



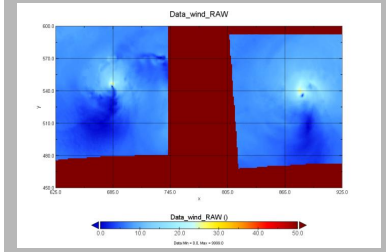
Combined Forecast



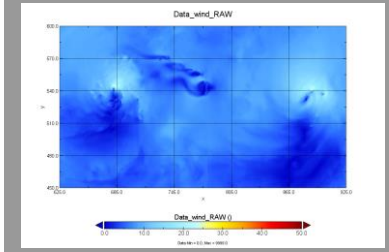
NBM 50% Probability Exceedance Values



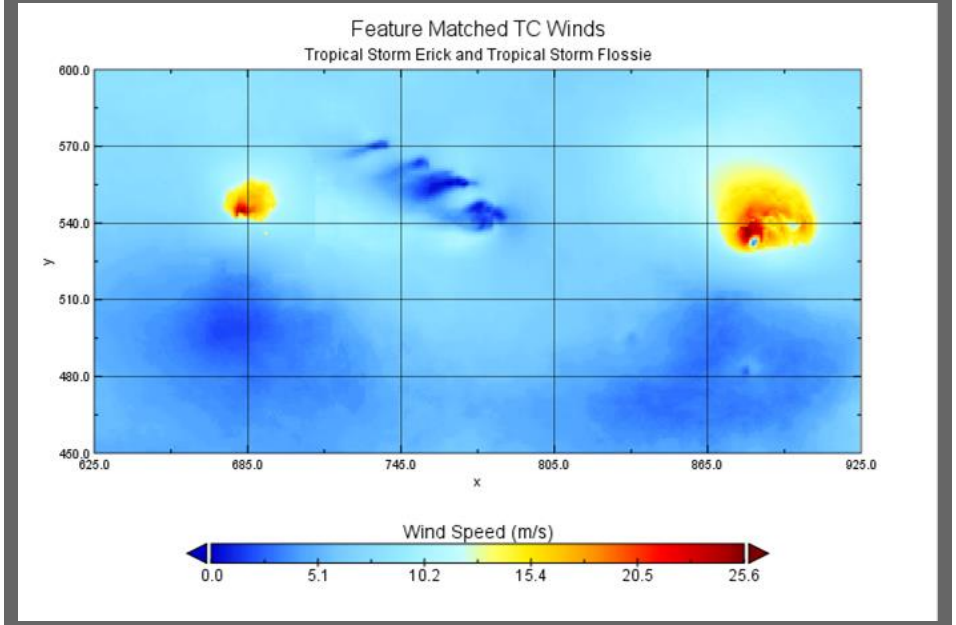
HMON

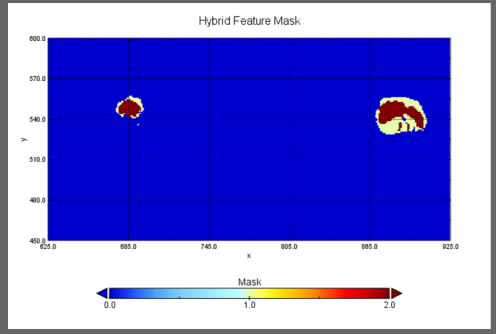


HWRF

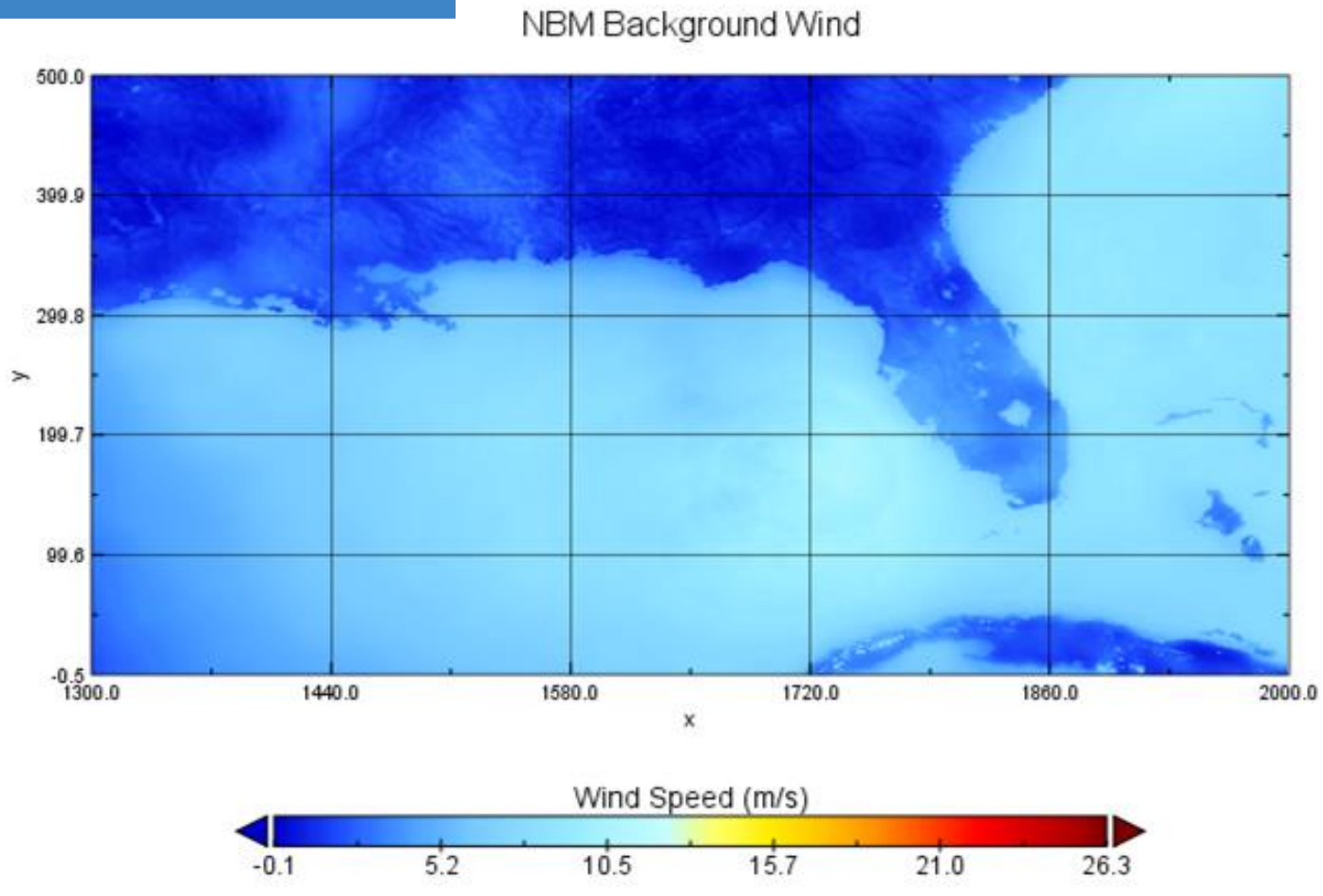


Combined WS Forecast (NBM + HMON + HWRF)

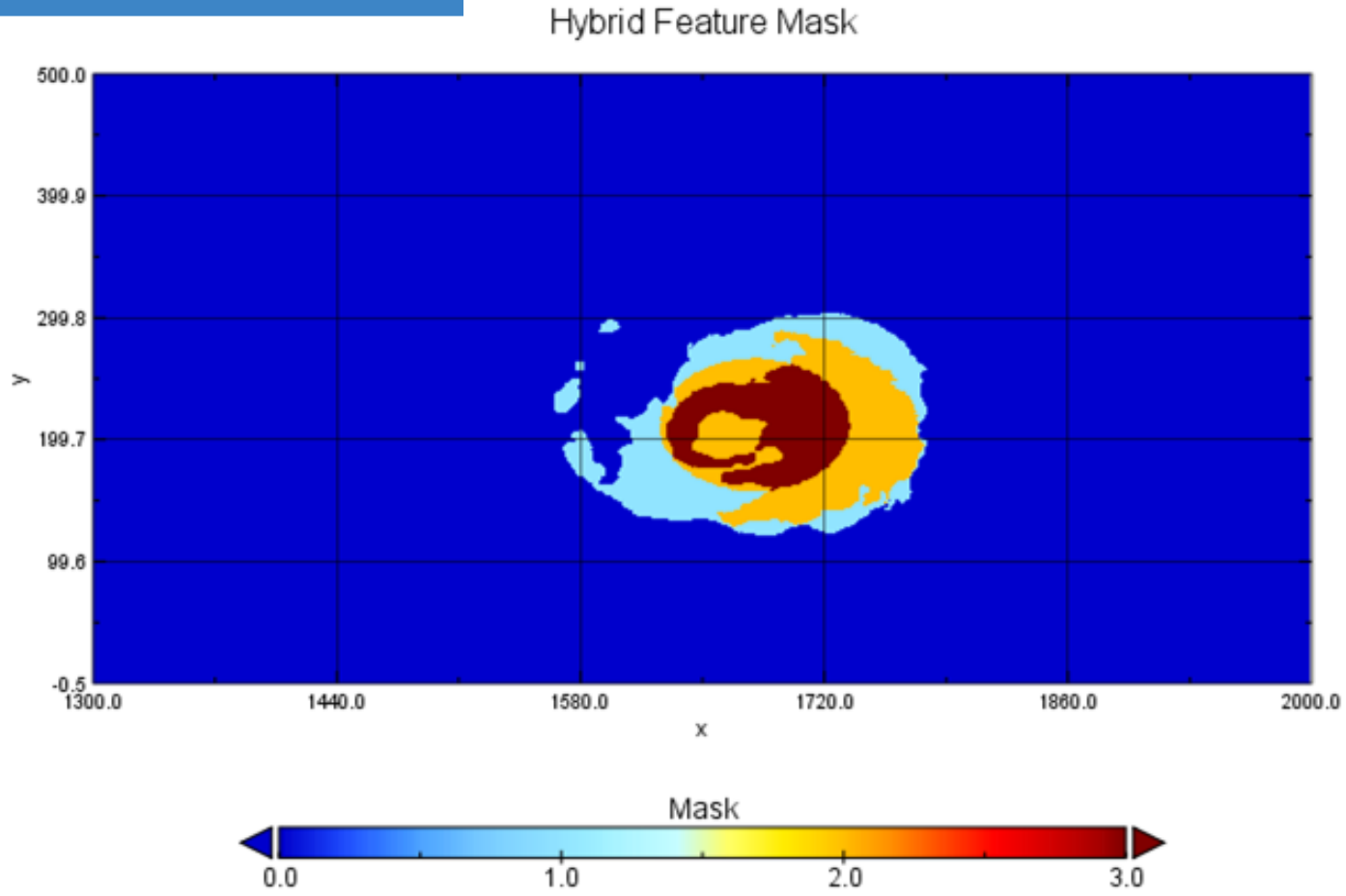




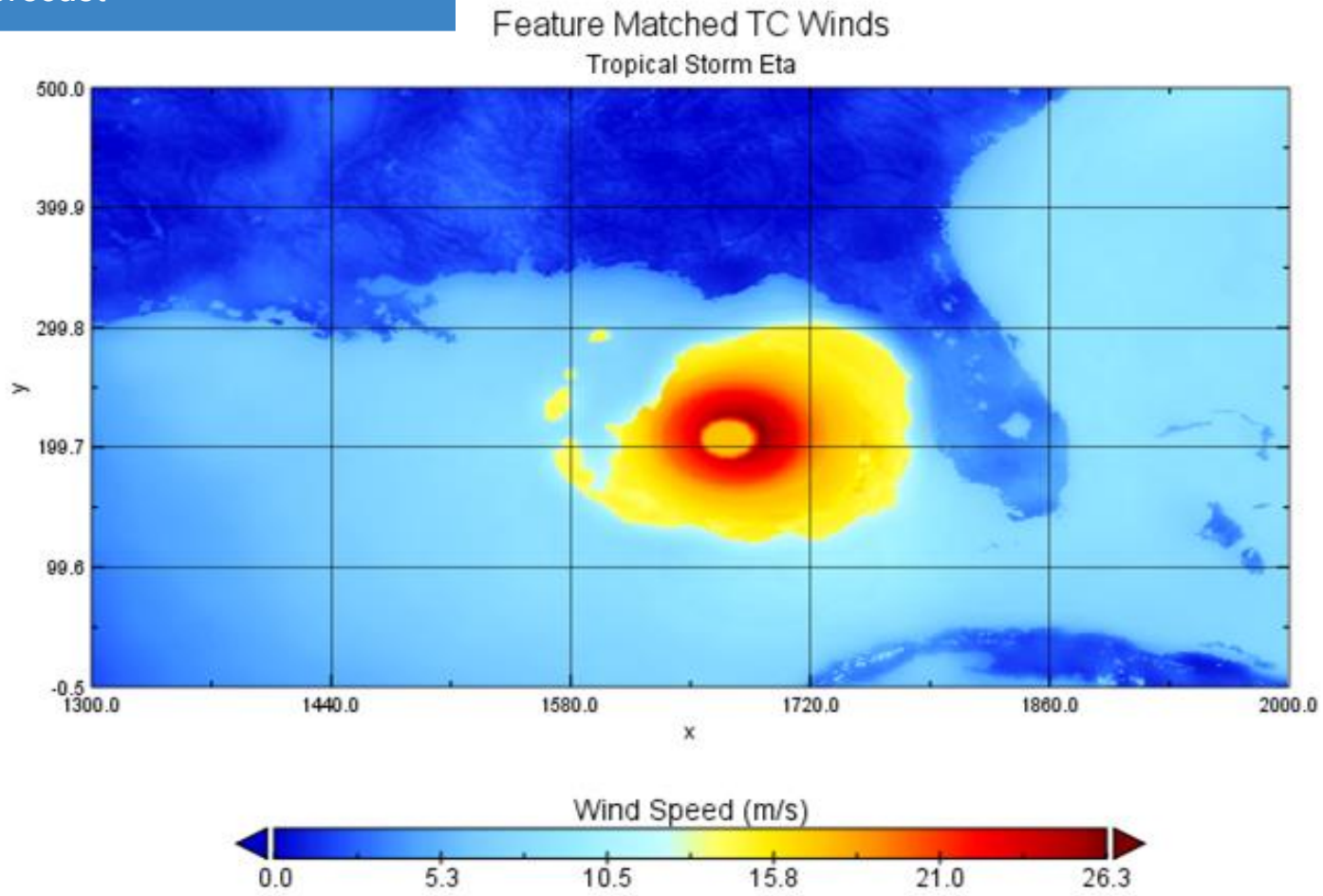
Oceanic Mean Wind Speed



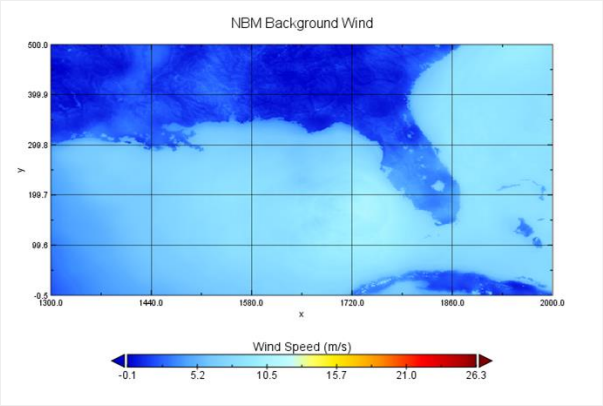
Hybrid Feature Mask



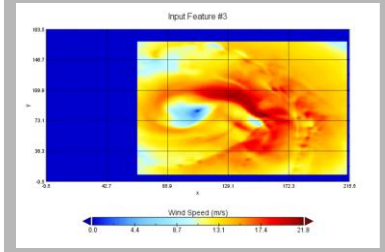
Combined Forecast

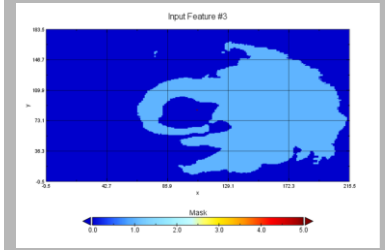


NBM Background

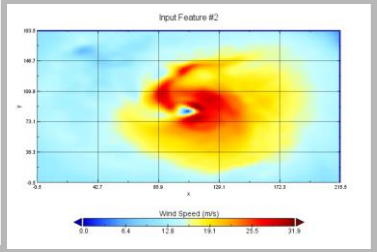


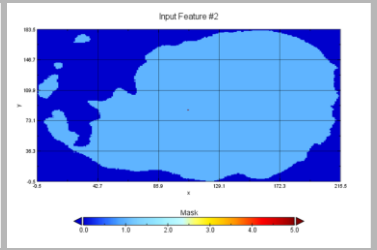
HMON



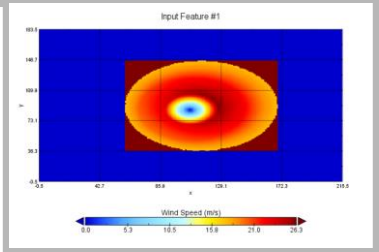


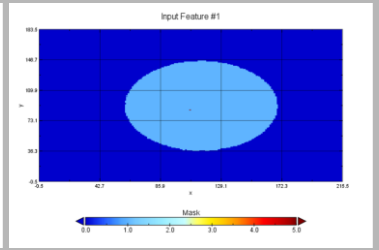
HWRF



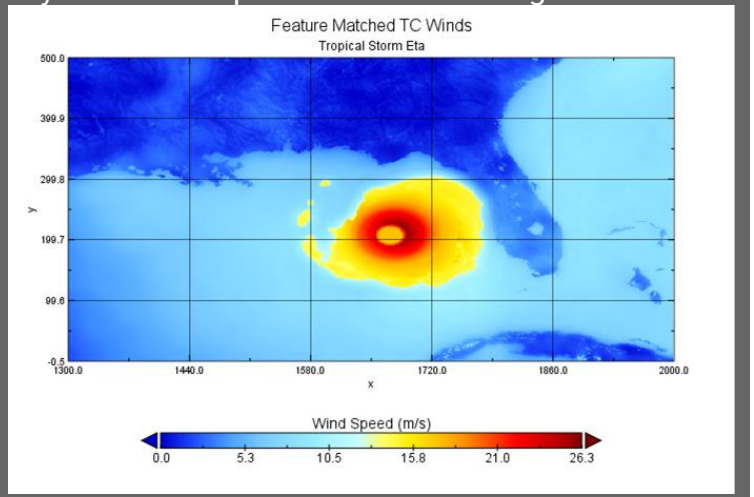


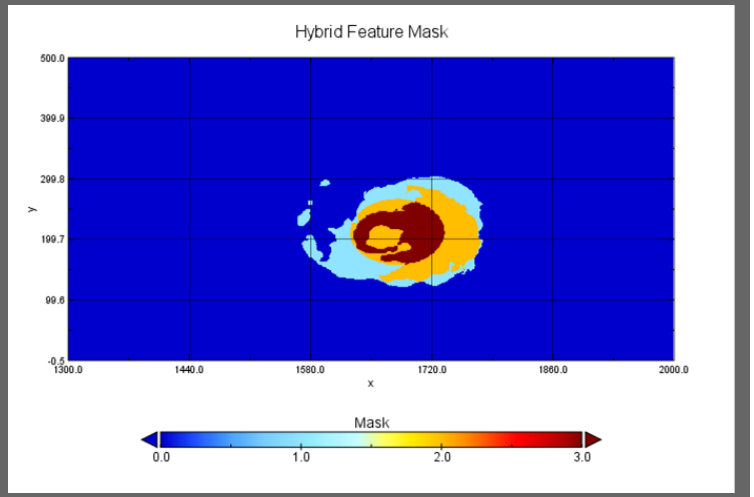
WTCM



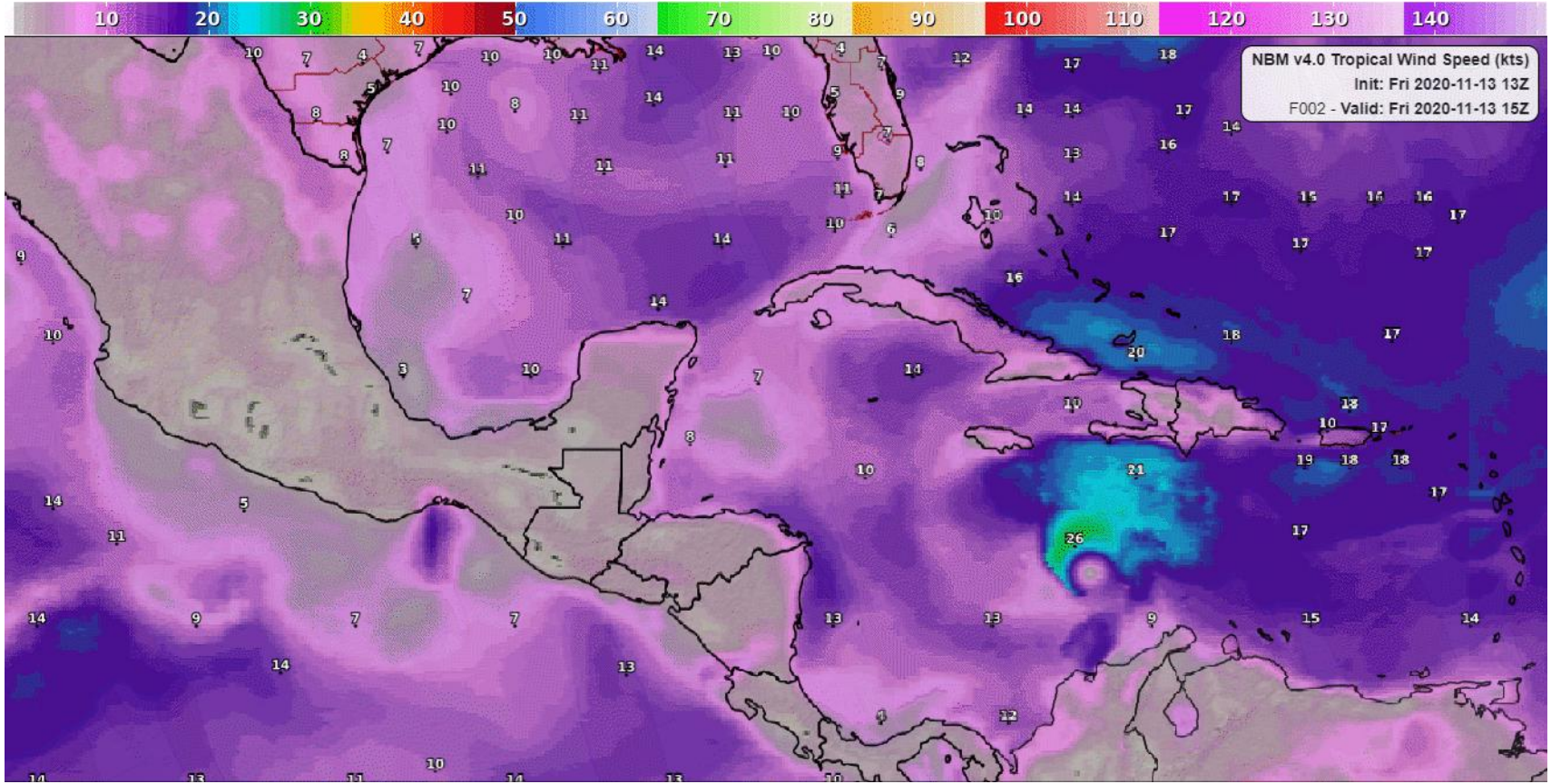


Hybrid Feature placed on NBM Background Winds

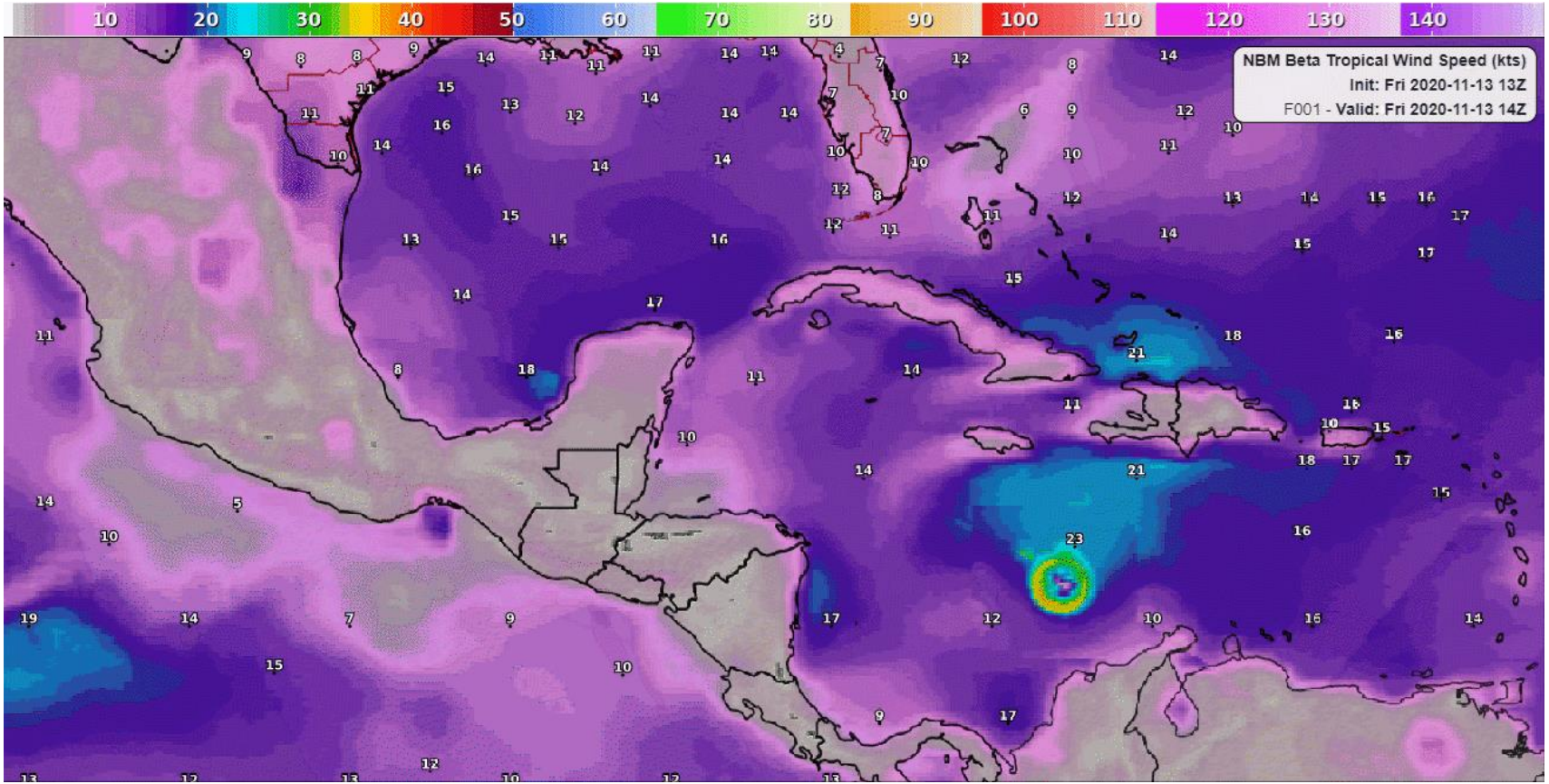




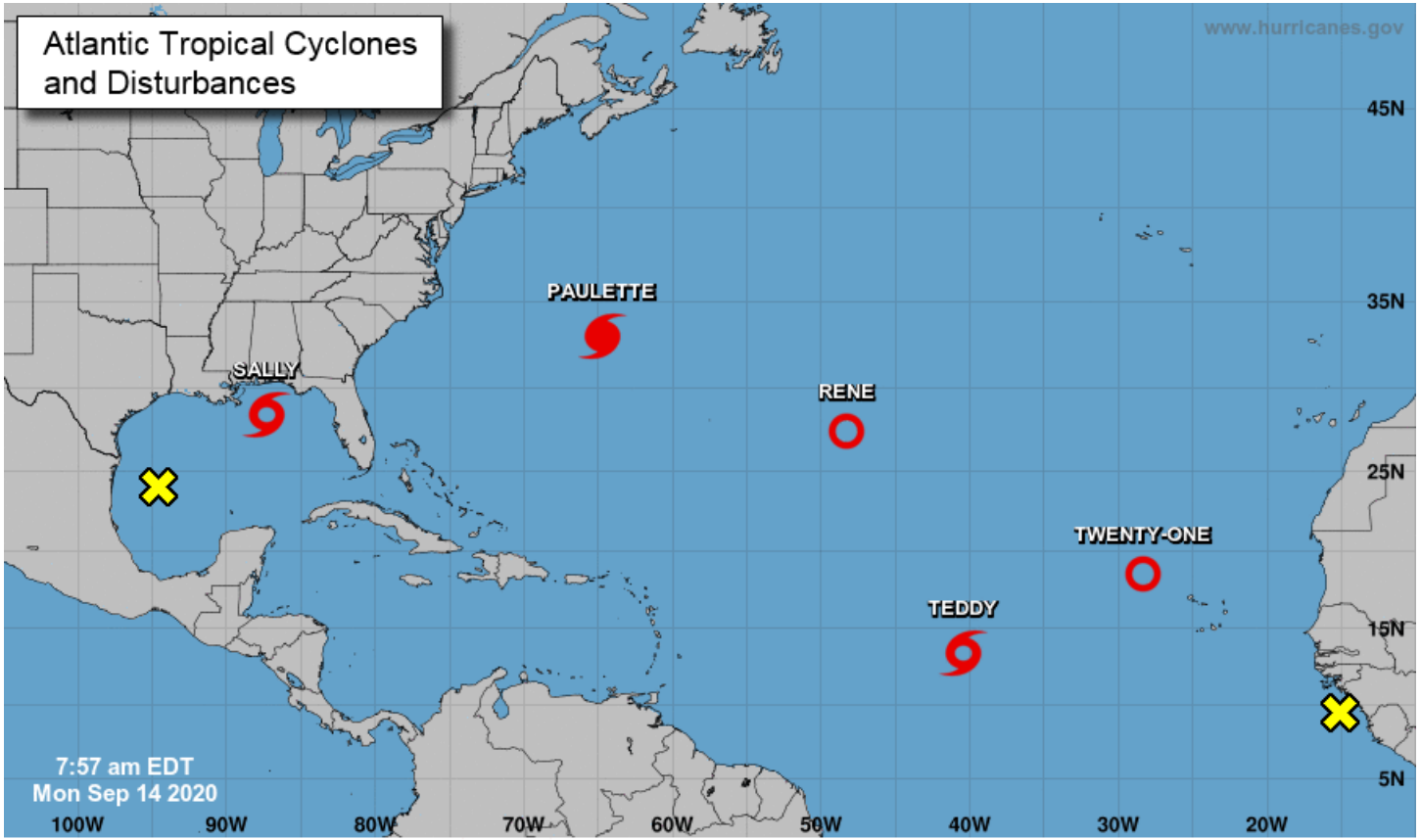
How do we fare with diverging solutions between DMO and wTCM?



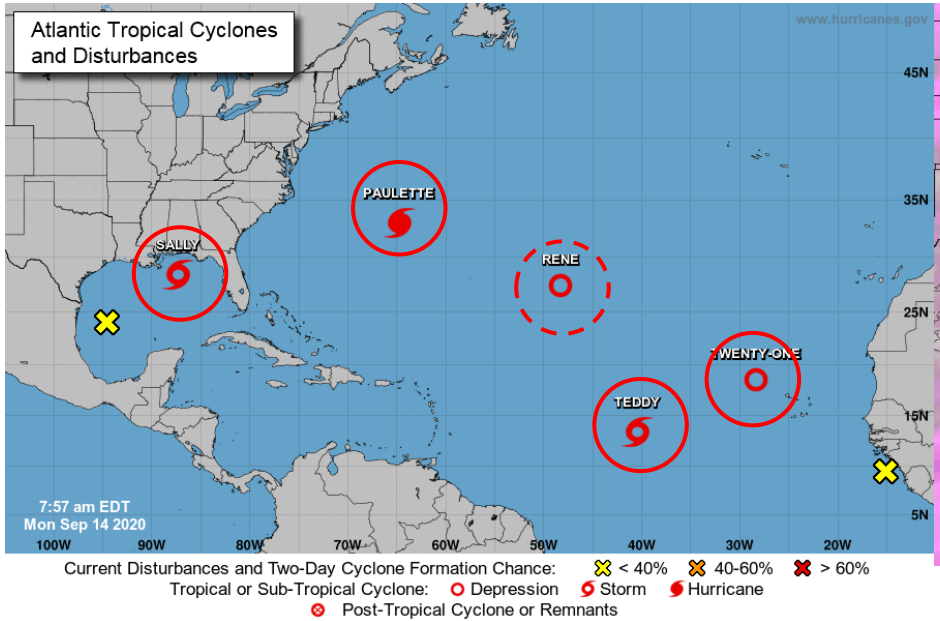
How do we fare with diverging solutions between DMO and wTCM?

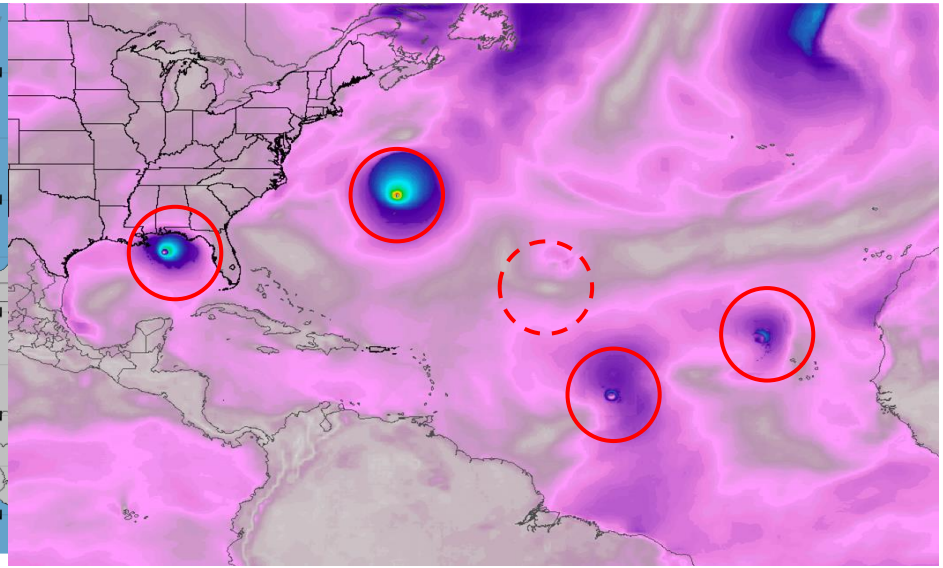


How do we fare in a multiple TC environment?



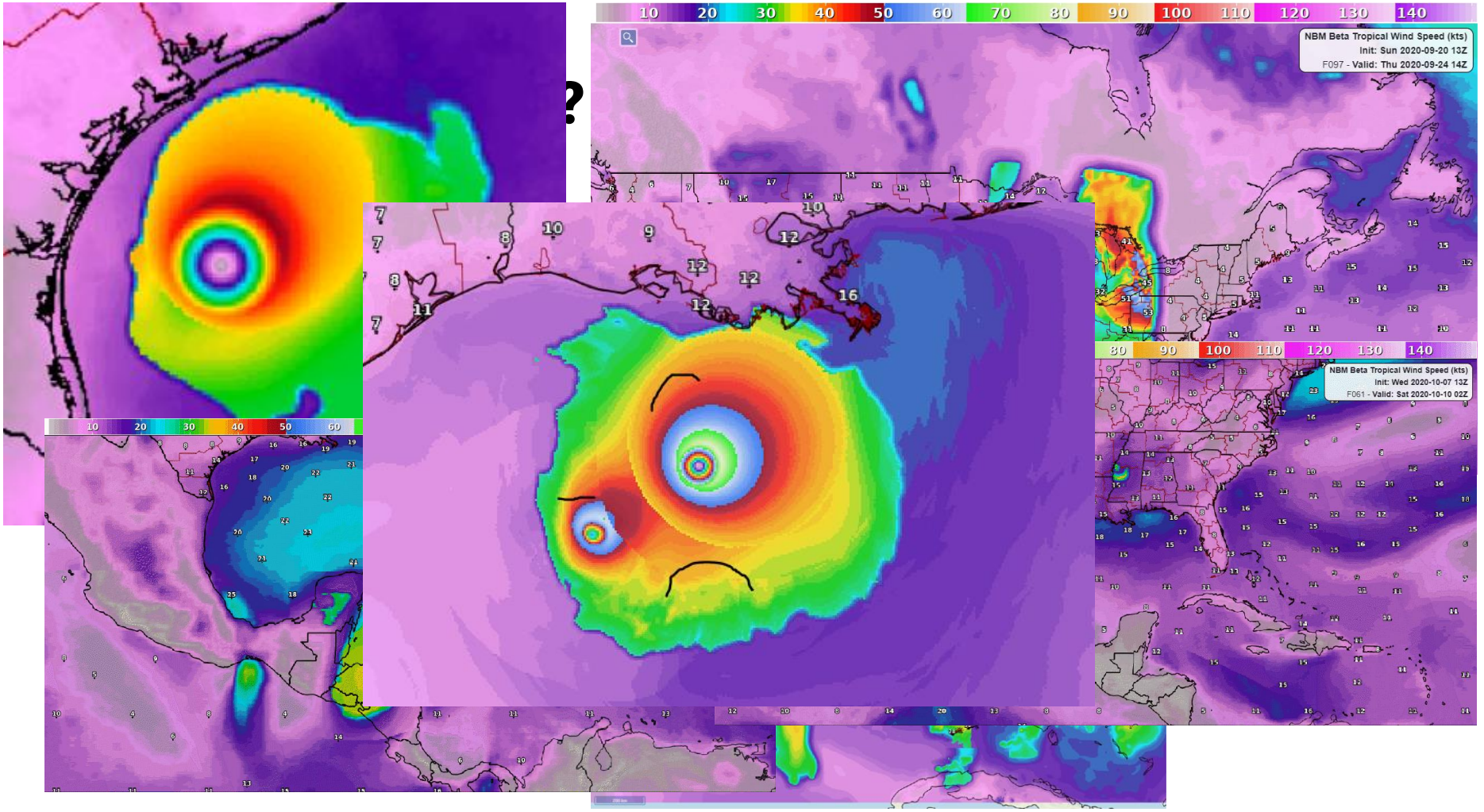
How do we fare in a multiple TC environment?





Conclusions

- Results from the wide variety of scenarios presented during the 2020 Atlantic hurricane season have been encouraging so far.
- Specifically, we’re pleased with the consistency of the matching algorithm and the visual presentation of the hybrid TCs.
- Feedback from our collaborators at NHC and AFS has been positive.
- We plan on evaluating more conclusively after the close of the season.
- We’ve highlighted some of our positive results here, but oddities can and do pop up.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NBM Beta Tropical Wind Speed (kts)
Init: Sun 2020-09-20 13Z
F097 - Valid: Thu 2020-09-24 14Z
80 90 100 110 120 130 140
NBM Beta Tropical Wind Speed (kts)
Init: Wed 2020-10-07 13Z
F061 - Valid: Sat 2020-10-10 02Z
10 20 30 40 50 60

Feature Matching Forecasts can be found on WSUP:

- http://wsup.mdl.nws.noaa.gov/ (NOAA Login Required)
- Select ‘NBM Beta’ for Dataset
- Tropical Speed (NBM Background + HWRF + HMON + wTCM)
  - Available for CONUS, Hawaii, Puerto Rico, and Oceanic domains
  - Run for 01z, 07z, 13z, and 19z
  - Guam domain is in the works!
- 10m Wind Speed (NBM Background + HWRF + HMON)
  - Available for CONUS, Hawaii, Puerto Rico, and Guam domains
  - Run hourly
  - Oceanic domain is in the works!

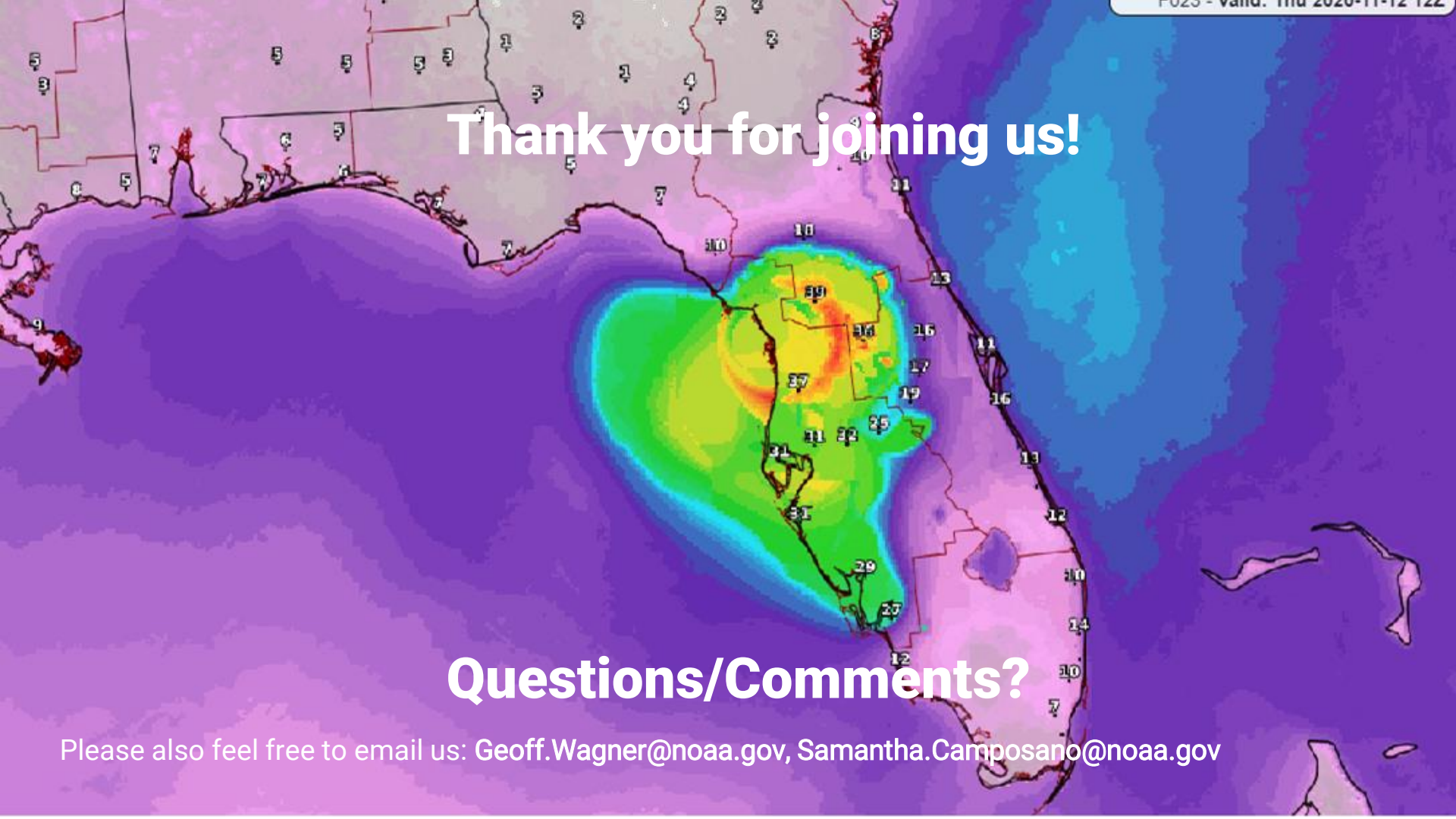
Future Plans

- This is still a Work-In-Progress; we are making improvements as we evaluate over this (unprecedented) hurricane season.
  - Refinements to matching logic
  - Land interaction considerations
  - Time interpolation of DMO Inputs in early lead times
  - Working on speeding up runtime by spreading computational load and leveraging existing compiled libraries where we can
  - Matching/calculating U-, V-Wind and Wind Gust in Hybrid Features for consistency
- We plan to implement with NBM v4.1 in Q2 of FY23.
- Forecasts will continue to be viewable on WSUP.
- We intend to also make GRIB2 data available for download next season.

Thank You

We want to thank all those who have helped support this work:

- The MDL, CIRA and AceInfo Solutions teams,
- Dave Rudack for his guidance,
- John Crockett for his guidance and help making this VLab Forum talk happen,
- Our colleagues at NHC and AFS for their invaluable collaboration,
- Our colleagues in the Can-US-UK Statistical Post-Processing Forum for their advice,
- The WSUP team for making it so much easier to evaluate and share our forecasts, and
- Our MDL-SMD colleagues for their enthusiasm and the lively tropical discussions as we've shared our work.


Thank you for joining us!
Questions/Comments?
Please also feel free to email us: Geoff.Wagner@noaa.gov, Samantha.Camposano@noaa.gov